GENERAL BOTANY

WITH SPECIAL REFERENCE TO LIBERAL EDUCATION

BY

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ILLUSTRATED WITH 157 ENGRAVINGS

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PREFACE.

If a course in botany is to be made interesting and useful the material must be selected from some definite point of view and the methods of presenting it must be determined from the same point of view. Obviously the general course in botany in by far the larger number of colleges and universities should be related to liberal education rather than to the training of future botanists or to functioning as a service course in some of the applied sciences in which botany plays a part. If we think of liberal education as the training and development that enables human beings to understand and enjoy their environment, and implants in them a desire to work with their fellow beings to change that environment in the direction of the ideal, we have the point of view from which the material may be selected and the method of presentation determined in the course in general botany.

The manner in which this viewpoint has been used in this book is discussed in the introduction.

In the preparation of a textbook, the author must necessarily consult many books and periodicals, and the manuscript must have the criticism of many readers. The works most frequently consulted in the preparation of this book are those listed at the ends of the various chapters. Use has also been made of Jeffrey's *The Anatomy of Woody Plants*. The periodicals most frequently consulted are *The American Journal of Botany*, *The Botanical Gazette*, *Ecology*, *The National Geographic Magazine*, and *Science*.

Manuscript has been read by W. M. Atwood, W. S. Cooper, John Davidson, J. E. Guberlet, E. S. Harrar, Lena Hartge,

J. W. Hotson, A. H. Hutchinson, Trevor Kincaid, D. K. O'Leary, L. D. Phifer, H. V. Tartar, T. G. Thompson, and R. B. Wylie. All of the page proof has been read by W. M. Atwood and A. H. Hutchinson, and portions of it by John Davidson.

I have obtained by conversations with my colleagues, H. K. Benson, T. C. Frye, Rachael Hoffstadt, J. W. Hotson, H. V. Tartar, T. G. Thompson, and John Weinzirl many facts which have been incorporated into my presentation of botany in this book.

My wife has given encouragement and assistance throughout the preparation of the manuscript and the reading of the proof. The index has been prepared by Charlotte Rigg. Raymond Rigg has assisted in reading both manuscript and proof.

The sources of most of the illustrations are stated in the legends. The photographs not specifically acknowledged were mostly purchased from Asahel Curtis and L. G. Linkletter. A few are by the author or were taken under his direction.

Grateful acknowledgment is made to all who have assisted.

G. B. R.

SEATTLE, WASH.

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INTRODUCTION.

This book is written from the viewpoint of the relation of botany to liberal education, and it is hoped that the spirit of this runs through all the pages. There are certain specific ways, however, in which this point of view has been emphasized. These may be stated under ten heads.

1. Attention is given to the important generalizations of the science. Though many facts about plants are interesting in themselves, facts are mainly important to the student when he is led to see that they help to establish generalizations, or that they do not at present fit into any generalizations, hence represent important starting-points for further progress in understanding our environment. The science of botany does not consist of isolated facts about plants, but of these facts arranged and related in such a way as to bring out general truths or laws.

2. An account of scientific method as used in the study of plants is presented, and emphasis is given to the fact that botany is not a finished science and that scientific method will be the guide to further progress.

3. The historical method of approach is used as far as is possible within the limits of a textbook. Much interest attaches to the ways in which the general laws of plant science have originated and the modifications that they have undergone in arriving at their present form. Some of the steps in the development of these generalizations are traced, and emphasis is given to the viewpoint that generalizations are not born mature, but are the result of growth.

4. The functional viewpoint is emphasized as far as possible. Facts about form and structure are interesting mainly when correlated with the processes that go on in the plant.

5. Plants are presented (Part III) from the lowest to the highest in order to bring out consistently the idea of evolu-

tionary development. The usual classification is used for convenience, but the emphasis is placed on such continuity of relationship as is well established and on the possible interpretations of the relationships of plants that do not fit completely into any interpretation so far suggested.

6. The general principles of the relation of plants to their environment are presented and examples are given to emphasize and clarify them. It is believed that an understanding of these principles contributes much to the understanding of our environment from the economic standpoint and also from the standpoint of enjoyment.

7. The relation of botany to other fields of knowledge is discussed. It has been found in several years of experience that students enter enthusiastically into the discussion of this subject, and the author believes that too little attention is usually given to the interrelation of the various fields of knowledge in liberal education.

8. The relation of plants to human welfare is outlined. No effort has been made to enumerate large numbers of useful or harmful plants, but the effort has been rather to state the general ways in which plants are useful or harmful to man and cite a few examples.

9. The discussions start with familiar plants and simple, direct methods of examining them as far as possible. Less familiar plants and more complicated methods are introduced afterward.

10. Everything is stated in simple and familiar language where possible. No effort is made, however, to avoid the use of technical terms where they are useful. Nothing is to be gained by the introduction of technical terms where the ideas can be expressed clearly and directly without them. On the other hand, technical terms when clearly defined are often useful in avoiding cumbersome phrases in descriptions and discussions.

The best results will undoubtedly be obtained in giving botany its proper place in liberal education where the laboratory work correlates with the general plan set forth above. Among the specific ways in which this can be done are the following:

1. The choice of common material. Selections may be largely made from the familiar plants of gardens, greenhouses, roadsides, pastures, woodlands and lakes, supplemented by selections of plant parts from the stocks of seedsmen, bulb dealers, grocers and fruit dealers. Such plants will naturally form the starting-point for the discussion of any plants that have not been seen by the student but still seem desirable to consider in the course.

2. The use of living material as the starting-point wherever possible. Most of the experimental work in the laboratory will necessarily be carried on with living material and the study of parts and external form is advantageously begun with living plants. The study of gross anatomy is readily carried on with living material as is also the study of microscopic anatomy to a considerable extent. It will be found, of course, that for certain details of structure properly preserved material and prepared slides will save much time for both teacher and student.

3. The exemplification of scientific method and the development of the love of truth in the laboratory work. The author believes that the methods used in presenting the laboratory work should emphasize training in skilful manipulation of materials, accuracy and freedom from prejudice in observation, the immediate and systematic record of data and careful thought as to the relation of the data to such generalizations as the student may be able to arrive at for himself, or as may be presented in the textbook or the lecture. Above all, the laboratory work should be a training in respect for truth, and students should record what their senses actually perceive. If sufficient time and attention are given by instructors and assistants to the selection and preparation of plants for the laboratory work material can usually be found that will clearly show the points wanted. At any rate, what the student actually perceives should be the starting-point for discussion and interpretation. There should, of course, be no temptation offered the student to misinterpret his data in any way in order to make them conform with what the textbook or the teacher may say. If carried on in this spirit the laboratory work will illustrate

the steps and the methods by which botany has come to its present state as a science.

4. The use of diagrams instead of detailed drawings wherever possible. It is the belief of the author that the amount of time ordinarily spent in making detailed drawings can be greatly reduced. In studying structure the relation of parts is easily shown in diagrams. Some small portions of the structure will need to be drawn in detail, and the relation of these to the other parts shown in the diagram can be readily indicated. Apparatus used in experiments can be shown in diagrams just as effectively as in drawings.

Field work is desirable in all of the phases of botany. Plants are interesting when they are growing actively, but many interesting facts that fit into the general scheme of plant study may be observed even when they are dormant. Field work may be made interesting at any time of year if students are encouraged to make their own observations and work out interpretations of the facts observed.

Many of the methods here enumerated with reference to both the textbook and the laboratory work have been used to varying extents and in various ways by many teachers; the plan here presented is to correlate all of them in helping the student to understand and enjoy his environment.

COLLEGE BOTANY.

PART I.

THE STRUCTURE OF THE HIGHER PLANTS FROM THE FUNCTIONAL VIEWPOINT.

CHAPTER I.

PLANTS AS LIVING THINGS.

ORGANS AND THEIR FUNCTIONS.

PLANTS are living things and have certain points in common with all other living things. Among the more striking of these are: (1) they must have food and water; (2) they respond in certain ways to their environment; (3) they have some form of reproduction; (4) all except the lowest ones have organs suited for the performance of these functions.

In the main, ordinary green plants make their own food from raw materials taken in from the earth and air. Some of this they use in building up their parts, some they store to be utilized in resuming growth after periods of dormancy and some they break down and thus release energy which is used in growth and in other ways. They take in water which is necessary to maintain the form of their softer parts such as leaves, and is also necessary in other ways for their life.

FIG. 1.—Trilliums in forest humus.

It is evident that plants respond to such factors in their environment as light, temperature and gravity. Stems and leaves commonly grow toward light. They do not, however, always adjust themselves so as to get the maximum amount of light, but they do orient themselves in certain definite ways with reference to light. Plants show definite responses to temperature, some growing best at rather high temperatures, and others at lower temperatures. It is readily seen that many plants grow erect and that is a response to gravity.

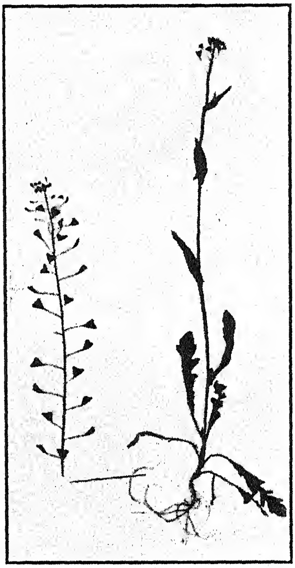

FIG. 2.—Shepherd's purse. Leaves, stems, roots, and fruits (pods).

If plants are to continue to exist, they must, of course, reproduce their kind. This reproduction varies from quite simple methods involving no specialized parts, to extremely complex methods involving highly specialized organs.

The higher plants (Fig. 2) are composed of parts called organs, which are suited by their external form and their internal structure to the performance of the various functions

that these plants carry on. These organs fall readily into two groups—those that are concerned with the work of the individual plant, and those that are concerned with the production of new individuals. In higher plants the organs of the first group are leaves, stems, and roots, and those of the second group are flowers, fruits, and seeds. The first group are called vegetative organs, and the second reproductive organs.

It is readily seen in examining the external appearance of these organs with the unaided eye that they are suited by their form for the performance of certain functions, and if we make sections of them and examine these with the unaided eye and then with a hand lens and finally with a compound microscope we see that their internal structure as well as their external form fits them for their work. On looking at such leaves as those of a maple tree, a pansy plant, or a potato vine, we see that each leaf has a stalk on which is borne a rather thin blade which exposes a large amount of surface in proportion to its bulk. The form of this blade allows the ready penetration of light to its inner parts, and when we examine its structure we find that it is such as to facilitate the entrance of the oxygen and carbon dioxide from the air which are necessary for the work of the leaf, and also to permit the return of any excess of these gases to the air.

The stems of ordinary plants, such as maple trees and field corn are fitted by their form and structure to support the leaves in a position suitable for their work and to maintain a highway of communication for water and dissolved substances between the leaves and the roots. Roots are fitted by their form and structure to anchor the plant in the soil and to absorb from the soil the water and dissolved substances that are used by the plant in its life processes.

Though new plants are sometimes produced by planting pieces cut from the stems or roots or even by placing leaves in water or on moist soil, it is evident that the main work of leaves, stems, and roots is concerned with the welfare of the individual plant rather than with the production of new plants, and it is for this reason that they are called vegetative organs.

The above discussion does not by any means contain a complete list of the functions of leaves, stems, and roots; it is merely the mention of a few of them to bring out the general principle that form and structure are related to function. The details of the structure and function of these organs are given in later chapters.

Most of the higher plants are reproduced by seeds. The forms of the seeds are usually such as to help them to resist mechanical injury and in some cases to secure dispersal. The rounded form of a sweet-pea seed illustrates the first point, and the tuft of hairs on a milkweed seed and the wing on a seed of the trumpet creeper, or of a pine, illustrate the latter. Since the seed contains the embryo of a new plant, provided in some way with a food supply, and its external parts are of such a nature as to furnish protection for this embryonic plant, it is evident that its structure is correlated with its function of reproduction.

The function of flowers is the production of seeds. Many flowers are valued by human beings for their beauty, but their function so far as the plant is concerned is reproductive. A complete flower is composed of several parts, some of which play a very direct part in the production of seeds, while others play a less direct part. Pollen grains, familiar to us as the yellow powder commonly seen on flowers, and small bodies called ovules (Fig. 51), produced in a cavity in the base of the central portion of the flower, are essential bodies in the production of seeds. A growth from the pollen grain must reach the ovule in order to insure the production of a seed, and the form of the flower and its parts is usually related very definitely to this, as is also the structure of the parts producing the pollen and the ovules.

Seeds are contained in fruits (Fig. 64). The word fruit is used here in a technical meaning, and a fruit in this sense may not be anything that we would popularly call a fruit. An apple is called a fruit by both the botanist and the fruit dealer; a bean pod is called fruit by the botanist but not by the grocer. In many cases the form of the fruit secures the dispersal of the seeds which it contains. Many seeds are readily carried by the wind. The winged fruit of

the maple (Fig. 65) and the small seed-like fruit of the dandelion, with its parachute of hairs (Fig. 54), are familiar illustrations. Some fruits, such as those of the Scotch broom, break open violently and throw their seeds to considerable distances. Many other examples might be cited to illustrate the general principle that the form of fruits is often related to the dispersal of their seeds. Some fruits, such as those of the jimson weed, are fitted to protect their seeds until they are fully ripe and then to split open and discharge them. The structure of some fruits is such that they are suitable for food for birds or other animals and seeds are often widely distributed in this way.

Buds (Fig. 17), by their compact and rounded form and their somewhat hard covering, are fitted to keep out water during their dormant period and to protect themselves against mechanical injury. Internally they contain in embryonic form the parts that are to develop into a leafy branch or into the various parts of the flower. Their form and structure combine to guard their tender parts against sudden changes of temperature which might kill them, as well as against other dangers.

The above examples are sufficient to illustrate the general principle, that the form and structure of reproductive organs, like those of vegetative organs, are related to the performance of their functions. This leads naturally to the definition of the term organ as a part of a plant suited by its form and structure to the performance of some function or group of functions.

CLASSIFICATION OF THE ORGANS OF SEED PLANTS.

- Organs
  - Vegetative
    - Leaves
    - Stems
    - Roots
  - Reproductive
    - Flowers
    - Seeds
    - Fruits

CELLS.

All plants are composed of cells (Fig. 4), and the cell is the unit of both structure and function. Although very large cells occur in a few plants, those of the plants that we commonly know can be seen only with a compound microscope. Ordinary living plant cells have a somewhat rigid wall within which lie the softer parts of the cell. This soft interior part consists in a mature vegetative cell of a rather thin layer of protoplasm lying next to the wall and enclosing the vacuole which is a relatively large cavity containing a watery solution called the cell sap. Somewhere in every cell there is a denser mass of protoplasm, the nucleus (Fig. 3). This nucleus may be embedded in the protoplasm, or it may be situated in the center of the cell and connected by threads of protoplasm to the outer layer of that material.

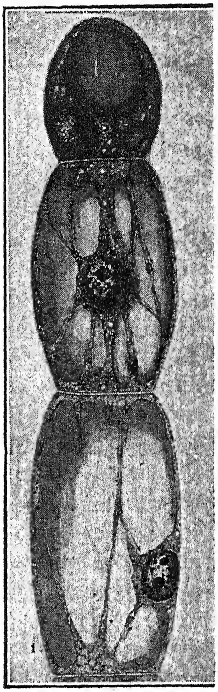

FIG. 3.—Cells from a hair of a stamen of spiderwort (*Tradescantia virginica*). The terminal cell shows cell wall, protoplasm, and three vacuoles. Each of the others shows one large vacuole, a large nucleus with a nucleolus, and a layer of protoplasm lying next to the cell wall and connected with the nucleus by thins trands in which the direction of the circulation is indicated by arrows. Highly magnified. (From Schmeil Botanical Charts.)

In ordinary cells of rather soft tissues, the cell wall is composed of a substance called cellulose. This is composed of three chemical elements (carbon, hydrogen, and oxygen), and belongs to the class of substances called carbohydrates, of which starch is a well-known example. In old cells, such as those of wood, where the living interior portion of the cell has disappeared, the wall is harder and is composed largely of a substance called lignin, which is chemically different from cellulose, though containing the same elements. Water penetrates rather readily into cell walls composed of either cellulose or lignin. In the corky cells

occurring at the surface of the bark of trees (Fig. 26) the cells are dead, and their walls consist of a substance called suberin which water does not readily penetrate.

Some cell walls are infiltrated with coloring matter. The wood of the yew tree is red and that of the hemotoxylon tree brownish-red due to the presence of pigments in the cell walls, and the heart wood of the Douglas fir has a somewhat reddish color for the same reason. Other cells, such as those of the scouring rush, contain a good deal of silica which causes the tissues to feel rough to the touch. Perforations by which the protoplasm is continuous from cell to cell are visible in many walls, such as those of the storage tissue of the seed of the vegetable ivory palm and of the cortex of the stem of some species of mistletoe.

Protoplasm.—Protoplasm is a somewhat viscous material resembling the white of an egg. It is usually colorless or grayish-white. Protoplasm is not a single substance, but is a mixture of various substances, such as proteins, carbohydrates, and fats, and also contains inorganic salts. In its normal condition in the living cell it contains far more water than anything else. The physical condition of protoplasm is very important. In the living cell it is in a colloidal state. This colloidal state is distinguished from the crystalloidal state. Such substances as gelatin, glue, agar, and the white of egg are in the colloidal state, while such substances as sugar and common salt are in the crystalloidal state. In a colloidal solution particles are visible with the ultramicroscope, while none are visible in a solution of a crystalloid. Another distinction between these two kinds of solution is that a crystalloid will diffuse through a parchment membrane while a colloid will not. There are two kinds of colloidal solutions—those in which solid particles are dispersed in a liquid and those in which liquid particles are dispersed in a liquid. The former are called suspensoids, and are illustrated by glue in water, while the latter are called emulsoids, and are illustrated by very finely divided olive oil in water with some emulsifying agent used to keep the particles of oil from separating out. Protoplasm is now thought of as a colloid of the emulsoid type, and the proper-

ties of protoplasm are best understood by considering it from the viewpoint of physical chemistry. This does not mean that an extensive knowledge of physical chemistry is necessary in order to get a general knowledge of protoplasm, but rather that a few of the general ideas of this science, such as those presented above, furnish the best basis for an understanding of the nature of protoplasm, and the part that it plays in the functions of the plant.

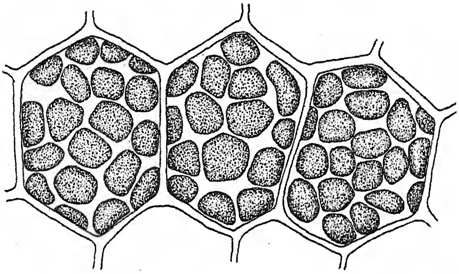

FIG. 4.—Cells of a moss leaf, showing cell walls and chloroplasts. (Drawn by M. W. Phifer.)

The name protoplast is applied to all of the plant cell except the wall, and this name is often used instead of cell when we wish to emphasize the cell as a living unit of the plant. The outer surface of the protoplast differs in some ways from the interior portion and is called the plasma membrane. The inner surface of the protoplasm where it comes into contact with the vacuole also has some distinguishing properties, and the term vacuolar membrane is applied to it. The portion of the protoplasm not included in the nucleus is designated as the cytoplasm, and the surface where the nucleus and the cytoplasm come into contact is called the nuclear membrane. Various bodies known as plastids are embedded in the cytoplasm. The green ones (Fig. 4), since they contain chlorophyll, are termed chloroplasts, while the colorless ones are termed leucoplasts.

The Nucleus.—The nucleus is visible under the microscope in many cells without any special treatment (Fig. 3)

and in others it may be made visible by staining with some substance, such as iodine. When a cell divides and forms two new cells the nucleus always divides, and thus forms a nucleus for each of the new cells.

A nucleus which is not in the process of division is called a resting nucleus. It consists of the nuclear plasma, the network of chromatin, a small round body called the nucleolus, and the nuclear membrane. Nuclear division takes place in two ways: (*a*) Indirect division, which involves the formation of bodies called chromosomes from the chromatin network; this phenomenon is called mitosis, or karyokinesis. (*b*) Direct division, which does not involve the formation of chromosomes; in this kind of division a constriction appears, the nucleus separates directly into two portions, and two new nuclei are thus formed.

Indirect division (Fig. 5) is the common method in the formation of new cells in vegetative tissues. It is readily seen in sections of growing root tips, and also occurs in leaves, stems, flowers, seeds and fruits. This phenomenon involves a number of visible changes which may be stated separately though they do not occur as entirely separate steps but overlap somewhat: (1) The formation of chromosomes from the chromatin network of the resting nucleus. (2) The migration of these to a central plane in the nucleus. (3) division of each chromosome by longitudinal splitting into two equal parts, called daughter chromosomes. (4) The formation of two polar caps in the cytoplasm, one cap situated at each pole of the nucleus. (5) The disintegration of the nuclear membrane. (6) The formation of spindle fibers, some of which (mantle fibers) extend from the poles to the chromosomes, while others extend from pole to pole, outside the chromosomes. (7) the disappearance of the nucleolus. (8) The formation of a central plate. (9) The movement of the chromosomes from the central plate to the poles. (10) The disappearance of the chromosomes and the formation of a new chromatin network in each daughter nucleus. (11) The formation, in the position formerly held by the central plate, of a wall separating the two new cells. (12) The formation of a new nuclear membrane around each of the

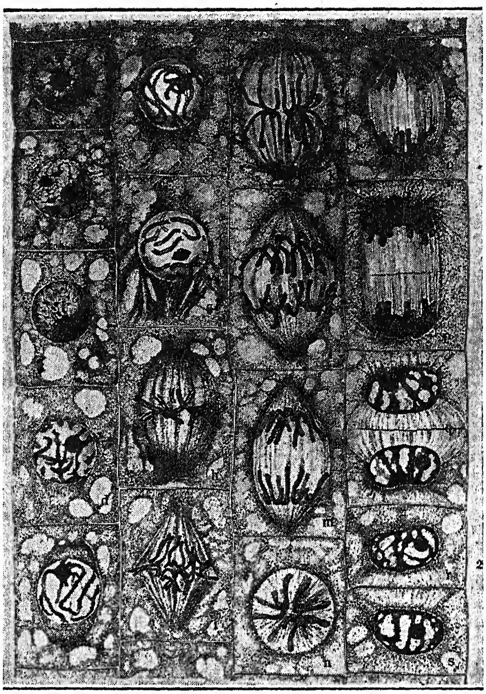

FIG. 5.—Indirect (mitotic) nuclear division as seen in cells of an onion-root tip. *a*, young cell completely filled with protoplasm; *b*, somewhat older cell in which vacuoles appear; *c*, mature cell with larger vacuoles, but with nucleus still unchanged; *d*, the chromatin forms band-shaped bodies (the beginnings of the polar caps are seen in the cytoplasm); *e*, the chromatin band has become consolidated and is radiating from the nucleolus; *f*, the chromatin bands show the beginning of longitudinal splitting (the mantle fibers appear in the polar caps); *g*, the chromatin bands break up by transverse divisions into chromosomes (the nucleus begins to dissolve; the mantle fibers are strongly developed in the lower portion of the cell); *h*, the chromosomes arrange themselves in the central plane, and form the so-called cell plate; *i*, longitudinal division of the chromosomes begins; *k*, each chromosome splits into two daughter chromosomes; *l*, the daughter chromosomes separate and move toward the poles; *m*, a somewhat later stage of development; *n*, the same seen from the pole; *o*, the chromosomes have reached the extreme polar ends; *p*, the daughter chromosomes begin to merge into the new nuclei (the first stages of the newly-formed cell wall are visible); *q*, the fusion of the daughter chromosomes is complete (the young cell wall already touches the old cell walls; *r–s*, the new cells which have resulted from the division. (From Schmeil Botanical Charts.)

two daughter nuclei. (13) The appearance of a new nucleolus in each daughter nucleus. (14) The separation of the two daughter nuclei, and the completion of the wall separating the two new cells.

By this somewhat complicated process, the various stages of which are seen in Fig. 5, and are readily observed in properly prepared sections of an onion root tip, the chromatin material of the resting nucleus is equally distributed to each of the two daughter nuclei. This is commonly accepted as the mechanism by which the characters of parent cells are transmitted to the new cells formed.

Direct division is comparatively rare. It is seen in certain cells which serve a nutritive function in the developing anthers of flowers, and in this case is not followed by the formation of a new cell wall, so that the two new nuclei both lie within the old wall. It also occurs in the formation of new cells in the outer tissues (cortex) of some seed plants that live submerged in water, and in the formation of new cells in yeasts by the process of budding (see p. 218).

The General Characters of Some Common Cells.—A knowledge of the nature of plant cells may be readily obtained by examining a few under a compound microscope. If the leaf of a common moss (Fig. 4), such as *Mnium* or other moss growing in damp places, is mounted in water on a glass slide and covered with a cover-glass the cell walls appear colorless, and the numerous green chloroplasts are seen embedded in the protoplasm in each cell. The nucleus and the vacuole are not apparent in these cells. Some further idea of these cells may be obtained by mounting them in a solution of common salt instead of water. When placed in this solution the chloroplasts are no longer distributed throughout the cell, but are drawn together in the center of the cell or at one side. Water is drawn out of the protoplast by the salt solution, and the protoplast shrinks away from the wall by its elasticity, its volume after the withdrawal of water not being sufficient to fill the whole space within the wall. The water is mostly drawn from the vacuole, but possibly some is withdrawn from the protoplasm also. The margin of the protoplast where it is drawn away from the wall may be

readily seen. The phenomenon of the shrinking of the protoplast so that it draws away from the wall when placed in a solution such as common salt is called plasmolysis, and a cell in this condition is said to be plasmolyzed. Cells may be plasmolyzed by many other solutions beside common salt. Cane sugar and potassium nitrate are commonly used. Any crystalloidal solution that does not penetrate the plasma membrane will plasmolyze a plant cell if its concentration is greater than that of the cell sap.

Plant cells are of various shapes. Many of the cells of a moss leaf show a somewhat six-sided form. This is due to the pressure of the surrounding cells in the process of growth. Such cells when first formed tend to assume a spherical form, unless pressed upon by other cells or otherwise modified by the conditions of growth in the leaf. If these round cells are of uniform size each cell will be pressed upon by six other cells during growth. This may be illustrated by placing a penny on the table and placing other pennies around it. It is seen that six pennies just fill the space around the first one and that these six are all in contact. The cells near the margin of the leaf are not pressed upon so regularly by other cells, and thus assume different forms. The cells in the central line of some moss leaves are elongated during growth. It must not be forgotten that a cell has three dimensions, and that we are considering only two in the above discussion. The third dimension of such a cell is made evident by focusing the microscope on the chloroplasts at the surface of the cell, and then gradually changing the focus until these become dim and those in the central portions of the cell are clearly seen.

The circulation of protoplasm in a cell may be readily seen in a leaf of the common water plant *Elodea*. If a leaf is mounted in water the chloroplasts in at least some of the cells will be seen moving. The protoplasm seems to have a circular motion around inside of the wall, the chloroplasts being carried along in the stream. Protoplasmic streaming can also be seen in the cells of the hairs on the stamens of spiderwort (*Tradescantia*) flowers (Fig. 3).

Living cells are readily seen also in the hairs of some other plants. If a bit of the epidermis from a *Petunia* leaf is stripped off and mounted in water the hair is seen to be composed of several cells set end-to-end, the hair being only one cell wide. The nucleus and the streams of cytoplasm are seen in such a cell.

If an onion is cut in two and one of the thick leaf-like portions that compose it is selected from the inner portion, a bit of epidermis may be stripped from it and mounted in water to show certain features of plant cells. The walls are evident here and the nucleus is usually conspicuous. If it is not clearly seen it may be made evident by removing the cover-glass and adding a drop of iodine. The absence of chloroplasts and the presence of other plastids is also seen.

A piece of bark removed from a small branch of a linden (basswood) tree is found to be quite flexible and fairly strong, and when it is bent the outer portion breaks much more readily than the inner. If a thin section is made lengthwise through the inner bark, and examined under the microscope, thick-walled, elongated cells, pointed at both ends, are seen extending lengthwise through it. These cells are better seen when the lignin test with phloroglucin and hydrochloric acid is applied. This is done by placing the tissue on a glass slide in a little water, then adding a drop or two of phloroglucin and, after two or three minutes, a drop of hydrochloric acid. With this treatment the cells become red, indicating that their walls are lignified. If a cross-section of this inner bark is made and treated in the same way it is seen that these cells occur in groups, and that the individual cells are round in cross-section, and have thick walls with a small cavity (lumen) within. These are called bast cells. They are dead cells, the living protoplast which was their essential part when they were young having disappeared. They give toughness, strength, and flexibility to the bark of trees and shrubs. These properties are especially marked in the bark of leatherwood, which was used by the Indians for thongs, and in the bark of the giant cedar which is readily stripped off in long pieces, and is used for temporary roofing of shelters in western forests.

The Progress of Knowledge Regarding Cells.—Plant cells were first seen a little over two and a half centuries ago, and for almost a century it has been known that all the parts of plants are formed by cells. It was in 1667 that Hooke, with his crude microscope, found that cork is composed of the structural units which we call cells. The cell wall, of course, attracted his attention first, but he also saw what he called juices in the cells. He seems to have thought of these juices as the real cells and of the walls as separating them from one another. Later the wall was thought of as

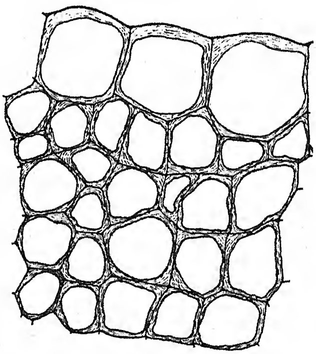

FIG. 6.—Cross-section of collenchyma and epidermis (three cells at top) of *Rumex* petiole. The collenchyma cells show the characteristic thickenings at the angles. The middle lamella between the walls of adjacent cells is shown. (Drawn by M. W. Phifer.)

the cell and everything inside it as the cell contents. Our knowledge of the living protoplast and of the wall which encloses it has come with the improvement of the compound microscope and the development of technique in its use. Much was contributed to this advance by Von Mohl in the years from 1830 to about 1860. He was skilled in the polishing and setting of lenses as well as in the preparation of tissues for examination under the microscope.

The chief difficulty in thinking of all of the parts of the plant as originating from cells had been in relation to the vessels, and also the latex tubes which are common in many

species of plants and contain milky material. Since these are continuous tubes of considerable length, and do not contain living protoplasm, it was not clear how they could be formed from cells. Von Mohl refused to accept conclusions arrived at on purely philosophical grounds, and made

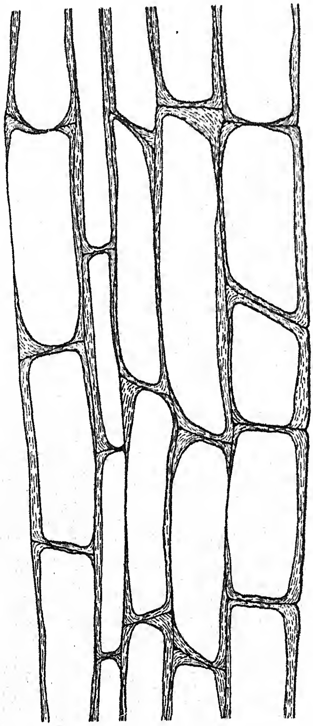

FIG. 7.—Longitudinal section of the tissues shown in Fig. 6. Epidermis at the right. (Drawn by M. W. Phifer.)

a careful study of these tubes, and found evidence that they were formed from rows of cylindrical cells placed end-to-end, the end walls of the cells as well as the living protoplasts degenerating and disappearing as the cells became older. He thus cleared the way for the acceptance of the idea that

all parts of the plant originate from cells, and the old idea that plants were composed partly of cellular portions and partly of tubular portions came to be viewed in its proper relation to Von Mohl's discoveries. In 1835 he described the first case of cell division, and we now recognize that all of the plant cells that we know come from the division of other cells. The origin of the first cells remains a matter of speculation. Interesting theories (see p. 324) as to the origin of living matter have been suggested, but we have no positive knowledge. Von Mohl also investigated the substance in the cell with which its properties as a living unit of the plant are associated, and gave it the name of protoplasm. The word protoplast was introduced by Hanstein, later. Many others contributed to the advance of our knowledge of the nature of the cell and the origin of plant tissues during Von Mohl's time, but his work stands out because of his skill, his patient work, and his refusal to accept conclusions not based upon observed facts. We must not discredit theory, for the formulation of theories is useful in guiding investigations along hopeful lines, and progress is rapid when bold thinking is accompanied by careful investigation of facts.

THE CELLULAR STRUCTURE OF SOME TISSUES.

Epidermis.—If a bit of epidermis is stripped from the blade of a dahlia leaf and examined under the microscope it is seen to be composed mainly of cells containing no chlorophyll. Among these are smaller curved or kidney-shaped cells, occurring in pairs with their concave faces toward each other. A pair of these cells with the opening that they enclose is called a stomate (Fig. 13), and the cells themselves are called guard cells. The guard cells are distinguished from the other epidermal cells not only by their shape but also by the fact that they contain chloroplasts. There are stomates in the epidermis of both the upper and the lower surface of a dahlia leaf, but in the laurel leaf the stomates are found on the lower surface only. Epidermis is present on many parts of plants, particularly while these parts are young. It is

also found on many mature organs when they consist largely of soft tissues. It is readily found on the surface of leaves, some of the parts of flowers, young stems, and young fruits. Stomates provide for the diffusion of gases from the air to the interior tissues. Epidermis is a protective tissue, usually one cell in thickness. When stems and other organs grow older the epidermis is frequently replaced by some other protective tissue, such as cork.

Chlorenchyma.—The tissues of a leaf blade, such as that of the house geranium (Fig. 12), may be clearly seen in a thin cross-section, mounted in water, and examined under the microscope. The colorless epidermis, one cell in thickness, is seen at the top and the bottom of the section. Between these two the green tissue (chlorenchyma) of the leaf is seen, and the chloroplasts are found to be numerous in its cells. In many common leaves, such as those of the calla lily and the house geranium (Fig. 12), the green cells next to the upper epidermis are elongated and stand parallel with their ends toward the epidermis. They form a rather compact tissue, and the intercellular spaces among them are small. Next to the lower epidermis in such a leaf the chlorenchyma cells are rounded or irregular in shape and the intercellular spaces are large. The tissue formed by such cells is called spongy parenchyma, and it gives the spongy character to such leaves as those of the calla lily and the beet. Leaves of various seed plants differ a good deal in their structure, as will be brought out in later chapters. The intention here is merely to bring out the nature of chlorenchyma.

Parenchyma.—If a thin section of the storage parenchyma from the interior of a potato tuber is mounted in water and examined under the microscope the cells are seen to be full of starch grains (Fig. 67). All that can be seen in this tissue is the cell walls and the starch grains. If dilute iodine is applied to this section the starch grains are colored blue while the cell walls remain colorless. This blue color with iodine readily distinguishes starch from other substances found in the cell. Storage parenchyma containing starch is common in plants. It is found in the sweet potato, the tissues forming the main bulk of the seeds of corn, wheat, and

beans, and in the underground stem of the bracken fern. Sugar is stored in the tissues of many plant parts, such as the roots of beets, carrots, and parsnips, and the fruits of peaches and pears. Oil is stored in the soft tissues of the castor-bean seed and in the flesh of the olive. Food storage is one of the important functions of parenchyma, and other foods besides starches, sugar, and oils are commonly stored in it. Parenchyma is a soft tissue whose cells are usually rather thin-walled and have their three dimensions about the same. In storage parenchyma the cell walls are commonly composed of cellulose.

Sclerenchyma.—If a thin cross-section of the stem of corn is examined under the microscope the hard outer portion is seen to be composed of dead cells with thick walls. If a drop or two of phloroglucin is applied to the section, and then a drop of hydrochloric acid, the walls of these cells become red, and this indicates that they are composed of lignin. The part of the cell seen here is the thick lignified wall, and the space within it called the lumen. Cells of this kind are called sclerenchyma cells, and the tissue that they compose is called sclerenchyma. This tissue in the corn stem is mechanical, in the sense that it gives support to the stem, and it is also protective. It sometimes occurs in the interior of soft stems as well as at the surface. The underground stem of the bracken fern shows sclerenchyma (Fig. 117) at the surface and also in two bands and many small strands extending lengthwise through the stem. Cells somewhat similar to these frequently occur in small groups or even singly in the fleshy or soft parts of plants. Such cells are called stone cells. Small groups of them constitute the gritty bodies found in the flesh of the pear, and extremely large irregularly shaped ones are found in tea leaves and in bark (Fig. 36). An easy way to find such cells is to apply the lignin test with phloroglucin and hydrochloric acid so as to render them conspicuous by their red color. Stone cells forming a continuous hard tissue (sclerenchyma) are found in the shell of the walnut.

Cork—Cork tissue is found as the covering of the bark of such woody stems as those of the willow, ash, and other

trees (Fig. 26). It is readily seen in cross-sections of the bark. In such a section the cells are seen to be rectangular in shape and arranged side by side in rows, the rows extending radially through the cork. The walls of these cells differ in composition from those of cells previously discussed. They consist of suberin, a substance that is somewhat fatty in its nature and does not wet readily with water, and corky tissue is thus fitted to protect the deeper tissues from the loss of water. Cork tissue, as mentioned before, displaces the epidermis of perennial stems as they grow older. It is also found on the surface of many fleshy organs, such as the potato tuber.

Conductive Tissue.—Conductive tissue in the form of vascular bundles is seen in a cross-section of the stem of corn (Figs. 18 and 19). The individual bundles are easily seen with the unaided eye, and when viewed with the microscope each one is seen to be made up of two general regions. One of these regions is characterized by a few large thick-walled empty cells, between which are smaller cells without any special characters to render them conspicuous. This region is termed xylem, and the large, thick-walled cells are called vessels. The other region is termed the phloem, and consists of regularly arranged, squarish cells with smaller cells, also squarish, occurring where the corners of the larger ones come together. The larger cells are called sieve cells and the smaller ones companion cells. Where the section has happened to be cut at the level of the end of a sieve cell the perforated sieve-like membrane forming its end wall may be seen. Such cells as are cut across at any other level than the end may not show any conspicuous contents.

In a longitudinal section of this bundle (Fig. 20) the vessels are seen as tubes extending lengthwise through the stem, and showing walls characterized either by numerous pits or by ring-like thickenings on their inner surface. A vessel is composed of a row of cylindrical cells arranged end-to-end, the living contents and the end walls having disappeared, so that the side walls form a tube continuous for some distance through the stem. The sieve cells are also seen, though they are less conspicuous than the vessels.

They are smaller than the vessels and their end walls are visible. They are arranged end-to-end in rows, and a row of them constitutes a sieve tube. Sieve tubes are more conspicuous in a longitudinal section of a vascular bundle of pumpkin stem (Fig. 20), and the perforated sieve-like character of their end walls may be seen, as may also their cell contents.

The vessels of corn may be more clearly recognized in both cross- and longitudinal section by applying the lignin test with phloroglucin and hydrochloric acid, thus giving them a red color. If still more detailed examination of these bundles is to be made it is best to use permanent mounts prepared by special means and stained so as to bring out the various cells. These may be prepared by trained persons in the laboratory, or they may be purchased from supply houses.

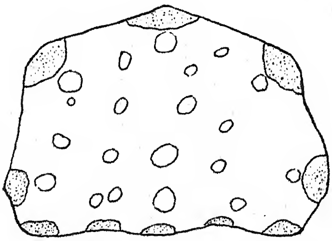

FIG. 8.—Diagrammatic cross-section of *Rumex* petiole. The boundary line represents the epidermis; the stippled areas just beneath it, bands of collenchyma; the circles, vascular bundles; the remaining portion, parenchyma. (Drawn by E. T. Bodenberg.)

Separate vascular bundles are here described because their parts are readily recognized. In perennial woody stems, such as those of willow and maple, the bundles are not separate, the wood being formed of the xylem, and the phloem being contained in the bark, which also contains other tissues.

Most of the movement of liquids and dissolved substances in the higher plants takes place in the vascular bundles. Water moves up the stem in the xylem, and there is considerable movement of diffusible organic materials in the sieve tubes and the adjoining parenchyma. It has been

commonly believed that the main movement of dissolved substances upward in the stem is in the xylem, but some recent work has tended to indicate that this occurs, at least to some extent, in the phloem.

Growing Tissue.—The growth of the roots and stems of such plants as beans and pines in both length and thickness takes place in very soft tissue (Fig. 37) whose cells divide rapidly and develop into the different cells forming the various tissues of the mature organs. Such a tissue is called meristem. Its cells are usually rectangular in form and have thin walls. It may be seen in longitudinal sections of stem tips or root tips. Here it gives rise, by division and differentiation of its cells, to the various tissues that do the work of these organs. The meristematic tissue by which the stems and roots of such woody perennial plants as the maples and the lilac grow in thickness year after year is the cambium. Cambium is also present in the vascular bundles of herbaceous stems (*e. g.*, beans), and all the xylem and phloem, except that originating from the meristem of the growing tip, is formed by it. It may be seen between the wood and the bark in cross-sections of the maple or the ash (Fig. 27) and between the xylem and the phloem of the separate vascular bundles in cross-sections of a pumpkin vine or of a young stem of birthwort (Fig. 29).

Collenchyma.—Collenchyma (Figs. 6 and 7) is a specialized living mechanical tissue common in rapidly growing organs, such as herbaceous stems and the petioles of leaves. In the petioles of the leaves of the common dock and celery it occurs in bands extending lengthwise just under the epidermis. In a cross-section of a *Rumex* petiole (Fig. 6) it appears as grayish-white lens-shaped areas between the chlorenchyma and the epidermis. The cells of the collenchyma are greatly thickened at the angles, so that the space within the wall, occupied by the living protoplast, is small and almost square. Collenchyma is found in the petioles of the leaves of sage, and also at the angles of the stem of catnip, and in the bark of the cascara tree, though the thickenings of the cells in the latter are not angular.

Collenchyma shows very few intercellular spaces. In

longitudinal section (Fig. 7) its cells are seen to be somewhat elongated. This tissue differs from sclerenchyma in being alive, and thus able to adjust itself to the growth of the adjoining tissues. Sclerenchyma consists of dead cells, and is the characteristic mechanical tissue of regions that are approaching the state of maturity where rapid growth ceases.

Summary.—By way of a summary it may be stated that plants are composed of organs, organs are composed of tissues, tissues are composed of cells, and a cell consists essentially of a nucleated mass of protoplasm, which is the physical basis of life. Organs are suited by their form and structure for the performance of certain functions, and the cell is the unit of both structure and function.

A list of the tissues discussed in this chapter is given below with one or more examples of each. This is not a complete list of the kinds of tissues found in plants, for some of these are best presented in connection with the more detailed discussion of the structure and functions of the various organs of different kinds of plants; it is intended merely to give emphasis to the idea developed in this chapter that organs are composed of tissues. A tissue may have more than one function, hence the same tissue in some cases appears in the classification under more than one head.

Classification of Tissues Discussed in This Chapter.

Synthetic tissue	Chlorenchyma
Storage tissue	Parenchyma
Conductive tissue	Xylem Phloem Parenchyma
Mechanical tissue	Sclerenchyma Collenchyma Bast Stone cells Xylem

CLASSIFICATION OF TISSUES DISCUSSED IN THIS CHAPTER.—(*Continued.*)

Protective tissue	Epidermis Cork Sclerenchyma
Growing tissue	Meristem of stem tips and root tips Cambium of woody perennial stems and roots and of some separate vascular bundles Meristematic tissues of leaves and other organs.

SUGGESTIONS FOR FURTHER READING.

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CHAPTER II.

LEAVES.

Ordinary leaves expose green tissue in a comparatively thin layer. The position of leaves on plants is usually such that light falls advantageously on the surface and the thinness of the layer of green tissue permits easy penetration of light to its cells. The structure of the leaf is such as to facilitate the exposure of green tissues to light and the exchange of gases between the leaf and the air. The outstanding characters of the leaf are its green color and its organization as a surface exposing organ.

THE PARTS OF THE LEAF.

Three parts are readily distinguished in many common leaves. The blade is the expanded portion, the petiole is the stalk on which the blade is supported, and the stipules are a pair of organs at the base of the petiole. All of these parts are present in some leaves, such as those of the roses (Fig. 10), the house geranium, the violets, and many of the willows. There are many leaves, however, such as those of the lilac, the foxglove, and the rhododendron, that have no stipules. There are also some leaves, such as those of Solomon's seal and flax, that have no petioles. The blade is the one part that is always present in ordinary leaves, and the activities of the leaf center in it.

The Leaf Blade.

The leaf blade consists of soft green tissue exposed in a comparatively thin layer held in form by a framework of veins, which also function in translocation, and protected by a surface layer of cells called the epidermis.

Epidermis.—The epidermis (Fig. 13) protects the blade from mechanical injury, excessive loss of water, and excessive light. It is one cell in thickness. Its cells are of various shapes in the leaves of different plants, but they always fit together so as to leave no intercellular openings except at the stomates.

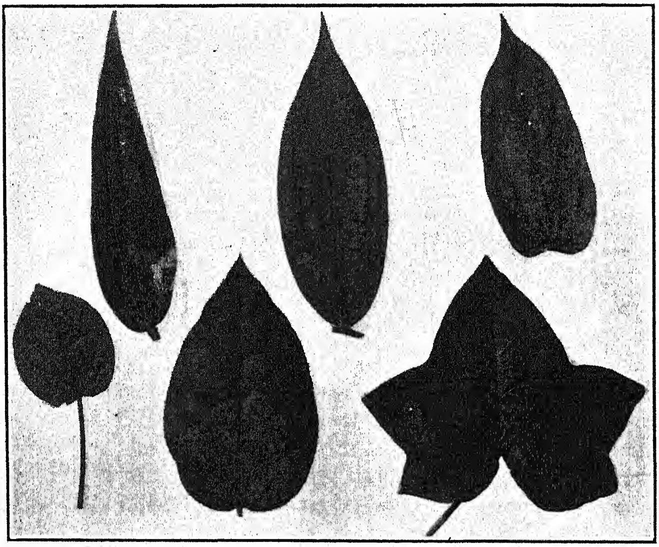

FIG. 9.—Simple leaves. Upper row; monocot leaves showing parallel venation. Lower row, dicot leaves showing netted venation. Upper left (*Lilium*), lanceolate with short petiole. Next, ovate-lanceolate with no petiole (sessile). Upper right, sessile with cordate base and acuminate apex. Lower left (*Pyrola*), broadly ovate with long petiole. Next (*Gaultheria shallon*), ovate-oblong with serrulate margin and short petiole. Lower right (ivy); lobed margin and cordate base.

Stomates.—A stomate is an opening through the epidermis surrounded by two kidney-shaped cells distinguished from the other epidermal cells not only by their shape but by the fact that they contain chloroplasts. They are placed with the concave side toward each other, and thus enclose the stomatal opening. The area of the opening between these

two cells varies with changes in their shape, and they are called guard cells. It is evident that the maximum size of the opening will be reached when each guard cell is semicircular in shape, and that the size of the opening will be reduced to zero if they become perfectly straight. The changes in the shape of these two cells are due to variations in the pressure of the protoplast on the cell wall. This is called turgor pressure, and is caused by the entrance of water into the protoplasm and vacuole of the cell. Increased turgor pressure causes stomates to open, and its decrease causes them to begin closing and, finally, to close entirely if the decrease continues. The conditions causing the amount of water in these cells to vary are discussed in the chapter on Physiology.

The mechanism of the opening and closing of stomates with changes in turgor pressure is connected in some cases with the shape of the guard cells, and in others with differences in the thickness of the different portions of their walls. If the guard cells are elliptical in cross-section when not turgid, and the walls are of uniform thickness, they become circular in cross-section when turgid and the stomate opens. A common type of thickening is that in which the wall on the concave side of the guard cell is thicker than that on the convex side. When turgor pressure is high in such a cell it becomes curved and the stomate opens. The mechanism of this may be illustrated by cementing a thick piece of rubber to one side of a piece of thin-walled rubber tubing and putting gentle water pressure on the tube by attaching it to a tap.

Stomates are very small. If holes are pricked in a piece of paper with a very fine needle it is found by microscopic measurements that the holes are very large in comparison with stomatal openings. Stomatal openings are usually slit-like instead of circular. The average size of the stomatal openings on the leaf blades of 38 species of common plants was found to be 17.7 by 6.7 microns. The micron is $\frac{1}{1000}$ of a millimeter, or about $\frac{1}{25000}$ inch, and is the standard unit of microscopic measurements. The largest stomatal openings (40 by 7 microns) in the 38 species referred to were

found to be in wheat and the smallest (6 by 3) were found in a greenhouse plant (*Abutilon*).

The leaf blade is a dorsi-ventral structure with usually considerable differences between the upper (dorsal) and lower (ventral) surfaces. One of these differences is in the number of stomates. Usually there are more stomates on the under surface of the leaf blade than on the upper, and in some leaves there are numerous stomates on the lower surface and none at all on the upper. In the leaves of *Begonia*,

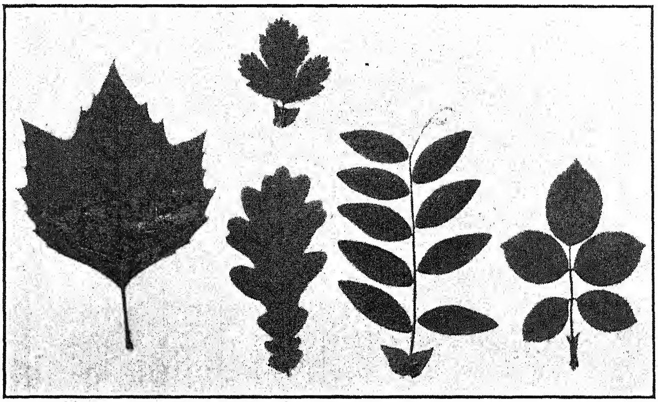

FIG. 10.—Simple and compound leaves. Top, a deeply-lobed simple leaf of avens with stipules. Left, a lobed, simple leaf of sycamore. Next, a lobed leaf of oak. Next, a pinnately compound leaf of vetch with stipules and tendril. Right, a compound leaf of rose with stipules.

Abutilon, the rubber plant, salal, lilac, cherry and Douglas fir the stomates are on the lower surface only. In the sunflower there are about twice as many stomates on the lower surface as on the upper, while in the Windsor bean the number on the lower surface is only a little larger than on the upper. In most leaf blades that have a somewhat horizontal position the number of stomates on the lower surface is considerably more than on the upper, but on erect leaves the number on the two surfaces is commonly about the same. Stomates on the lower surface of ordinary leaves

are less likely to be clogged by dust and rain than those on the upper, and they also allow less rapid loss of water. The average number of stomates per square inch on the leaves of the 38 species of plants referred to above was about 62,000. Stomates are usually scattered over the surface of the leaf blade, but in some leaves, such as those of some conifers and grasses they are arranged in rows.

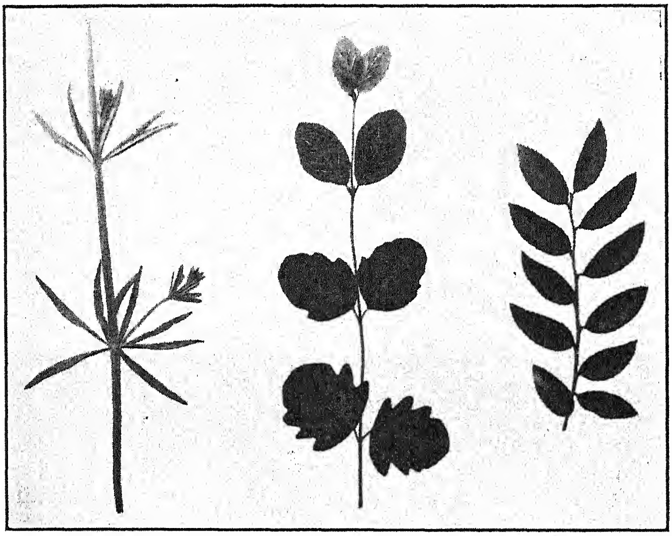

FIG. 11.—Arrangement of leaves. Left, whorled leaves of bed straw (*Galium*). Middle, opposite leaves of snowberry (*Symphoricarpos*). Right, alternate leaves of evergreen huckleberry (*Vaccinium*).

Leaf surfaces that are in contact with water usually have no stomates. The submerged leaves of water plants usually have no stomates at all, and floating leaves, such as those of water lilies have them on the upper surface only.

Cuticle.—A cuticle layer covers the surface of most of leaf blades, as it does also many other aërial portions of plants. This is a structureless layer of material, waxy in nature, originating from the epidermal cells. It is continuous, inter-

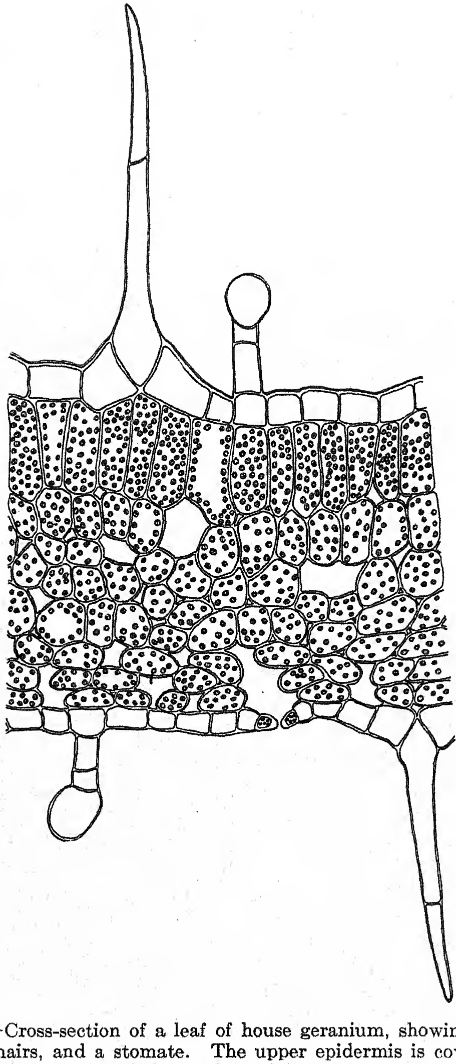

Fig. 12.—Cross-section of a leaf of house geranium, showing epidermis, mesophyll, hairs, and a stomate. The upper epidermis is covered with a cuticle layer. Two of the hairs are glandular and two are non-glandular. The layer of cells next to the upper epidermis constitutes the palisade, and the remaining portion of the mesophyll is the spongy parenchyma. The darkened circles in the cells represent chloroplasts. (Drawn by M. W. Phifer.)

rupted only at the stomates, and protects the leaf against excessive loss of water.

Mesophyll.—The green tissue of leaves is called mesophyll since it is in the middle of the leaf, and is also called chlorenchyma since it is green. The former term applies to the green tissue of leaves only, while the latter applies to the

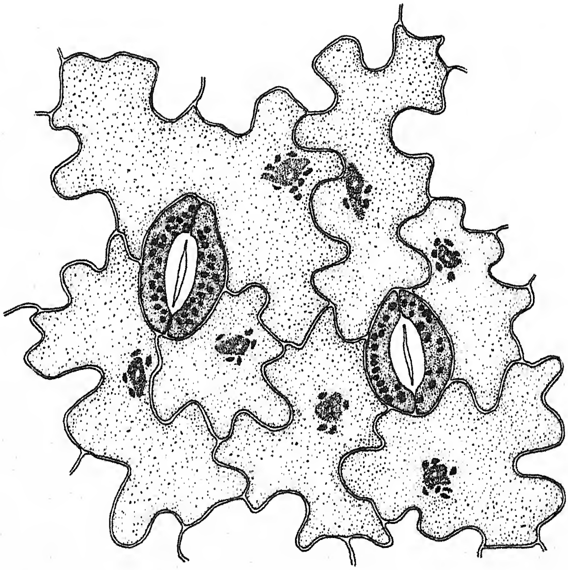

Fig. 13.—Surface view of epidermis of leaf of house geranium, showing two stomates. Chloroplasts are shown in the guard cells. The narrow slit shows the opening of the stomate. The space between this slit and the stippled portion of the guard cells shows the portion of the guard cell that was not in sharp focus in this view. The nucleus is shown in each epidermal cell. (Drawn by M. W. Phifer.)

green tissue of all plant organs. The mesophyll of many common leaves shows two fairly distinct regions, an upper and a lower. The upper portion is composed of elongated cells standing with the longer axis perpendicular to the epidermis and arranged so that the intercellular spaces are relatively small. This is called palisade tissue. Between

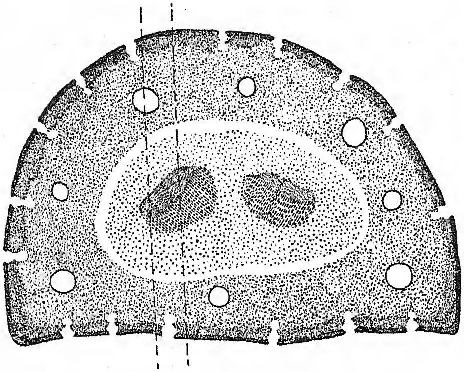

FIG. 14.—Diagrammatic cross-section of a pine leaf. The dark portion at the surface is the epidermis. The shaded area just beneath is the hypodermis (sclerenchyma). The unshaded circle is the endodermis. The mesophyll lies between the hypodermis and the endodermis. The eight circles show resin canals. The single vein composed of two bundles is shown at the center. The remaining portion inside the endodermis represents the transfusion tissue. The portion between the broken lines is shown in detail in Fig. 15. (Drawn by M. W. Phifer.)

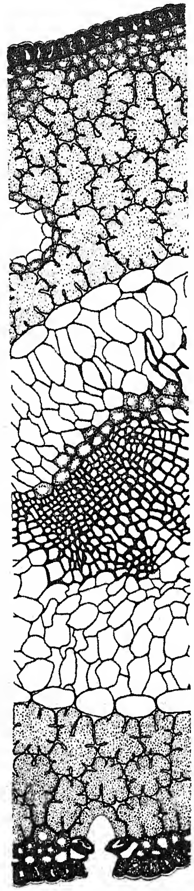

FIG. 15.—Detail of tissues shown between the broken lines in Fig. 14. The stomate at the bottom is the characteristic sunken stomate of the pines, the guard cells being beneath the epidermis. (Drawn by M. W. Phifer.)

this and the lower epidermis the cells are more rounded and are often irregular in shape so that the intercellular spaces are much larger. Such tissue is more yielding when pressed upon with the fingers, and is called spongy parenchyma. The large development of it in such leaves as those of beets and the calla lily gives them their spongy character. Some leaves, especially those that stand erect, have palisade tissue on both surfaces.

Beneath each stomate there is usually a space called the substomatal chamber with which the intercellular spaces of the mesophyll are in communication, and the exchange of the gases, carbon dioxide and

oxygen, between the leaf and the outer air is thus provided for and the movement of water vapor from the interior of the leaf to the outer air is facilitated by the same mechanism. The rate of such exchange and movement is, of course, regulated by the size of the stomatal openings and by the relative abundance of each gas, including water vapor, in the interior of the leaf and the outer air. The mesophyll of the leaf blade thus consists of moist cells in contact with an internal atmosphere which is in communication with the outer air through the stomates.

Water Storage Tissue.—Colorless tissue functioning in water storage is present in the leaf blades of some plants. In the leaves of *Begonia* and the rubber plant it occupies both sides of the leaf just beneath the epidermis, and the mesophyll is a thin layer between two layers of water-storage tissue. In this case the water-storage tissue also decreases the intensity of the light reaching the chlorenchyma. In the leaves of the gum weed the water-storage tissue is in bands extending through the mesophyll from the upper surface to the lower.

Veins.—The supporting framework of veins in a leaf blade is usually rather evident, especially if the leaf is held between the observer and a light. In many leaves the veins are more prominent on the under surface than on the upper, and in some there is even a slight furrow on the upper surface over each vein. The veins of leaf blades are arranged in four principal ways. In such leaves as those of the willows and wintergreen (Fig. 9) there is a prominent woody mid-rib from which the main veins branch off, and each of these veins gives off branches which join and form a network. Such leaves are netted-veined, and this kind of venation is seen in oaks, the lilac, and the dandelion. Some netted-veined leaves have several principal veins from the base, and the mid-rib is thus less prominent.

In such leaves as those of Solomon's seal and the grasses (Fig. 58) the veins are rather fine, and extend from the base of the blade to its tip without conspicuous branching (Fig. 9). In these leaves the mid-rib may not be very prominent. In the leaves of the canna and the banana there is a strong mid-

rib, and the parallel veins extend from this to the margin of the blade. Where the veins are unbranched and lie approximately parallel, whether they originate from the base of the blade or from the mid-rib, the venation is called parallel. Another arrangement of veins (Fig. 119) is that in which they come from a mid-rib, and fork, but their ends remain free instead of joining, as in netted-veined leaves. Such leaves are called free-veined, and this is the kind of venation found in the maiden-hair tree and in many ferns. In needle leaves, such as those of the pines (Fig. 14) and the firs there is only one vein, and it extends through the middle of the leaf from the base to the tip. We thus have four systems of venation: netted-veined, parallel-veined, free-veined and single-veined.

Whatever the form of venation, the veins serve the double function of support and translocation. It is obvious that soft tissue spread out in such a thin layer could not maintain its form without some mechanical support, and that the functions of the chlorenchyma could not be carried on without translocation of water and dissolved materials from the stem of the plant outward to all parts of the leaf blade and of manufactured materials from the leaf blade backward to the stem. The conducting tissues of the veins furnish considerable support, but they are usually accompanied by some mechanical tissue that does not function in conduction, and some leaf blades, such as those of the conifers, also have mechanical tissues that are not associated with the veins. In pine leaves (Fig. 15) there is a layer of sclerenchyma several cells thick just beneath the epidermis, whose thick-walled cells give rigidity to the leaf.

Endodermis.—In the leaves of many conifers there is a layer of cells called the endodermis, forming a sheath around the vein, but separated from it by some parenchyma tissue. The vein in these leaves is composed of two vascular bundles lying close together. The cells of the endodermis are living, and some portions of their walls are thickened and usually cutinized or suberized, sometimes lignified. The cells frequently contain starch and sometimes mucilage and tannin. When endodermis is present in leaves it constitutes a definite limiting layer between the vascular region and the mesophyll.

Resin Ducts.—Resin ducts extend lengthwise through the mesophyll in coniferous leaves. They are circular in cross-section (Fig. 15) and are surrounded by two layers of cells. They are formed by the separation of the leaf cells during their growth and are a part of a rather extensive system characteristic of the roots, stems, and leaves of many conifers and also found in some angiosperms.

Petioles.

The petiole is a stalk supporting the leaf blade and providing for the transfer of water and other materials between the leaf blade and the stem of the plant. It is covered with an epidermis which has stomates, and in general resembles the epidermis of the blade. Most petioles contain parenchyma tissue, and in many leaves this is green, especially when young. In some mature leaves the petiole is darker in color and more woody in structure. Vascular bundles continuous with those of the stem and with those in the veins of the leaf blade traverse the petiole. The mechanical function of support is provided for largely by these bundles, but in some petioles, especially those that support large blades, some collenchyma tissue is present. In the petiole of *Rumex* (Fig. 8) the collenchyma is in longitudinal bands just under the epidermis. The petiole is absent in some leaves, such as those of Solomon's seal, and in these the veins of the blade are direct continuations of the vascular bundles of the stem. A leaf having no petiole is called a sessile leaf. The leaves of grasses (Fig. 58) do not have a petiole in the form of a stalk, but have a basal portion that sheathes the stem of the plant, and there is a membranaceous projection called the ligule at the junction of the sheath and the blade, which prevents rain from running down between the sheath and the stem.

Stipules.

The stipules of many leaves, such as those of the sweet pea and the willows, are similar to the blades in structure and function. In some leaves, however, such as those of

the house geranium, the stipules lose their green color and become somewhat papery in texture as the leaf becomes mature. In the trailing blackberry and some other plants the stipules are very slender and bear little resemblance to leaf blades. In some plants the stipules are modified into rather specialized organs. Those of smilax are modified into tendrils which function in climbing, and those of the black locust take the form of spines. Stipules may be either deciduous or persistent. An example of the former is the basswood, in which the stipules fall off as the leaf becomes mature, and of the latter is the willow, in which they are present on the mature leaf. Stipules may be attached to the petiole through almost their entire length, as in the roses, or they may be attached by the base only, as in the blackberry. In the house geranium the stipules are attached to the stem of the plant.

THE PHYSIOLOGICAL FUNCTIONS OF LEAVES.

The physiological functions of leaves are the synthesis of foods from raw materials; the transformation of these foods in digestion and respiration; and the evaporation of water. All of these functions are also performed by other parts of the plant, and they are discussed in the chapter on The Functions of Plants.

DESCRIPTION OF LEAVES.

Many descriptive details about leaves are useful mainly in the identification and classification of the plants. Among these useful descriptive details about leaves are the form of the leaf blade and of its base, apex, and margin; whether the blade is all in one piece or is composed of separate parts; the venation of the blade; the presence or absence of stipules and their character when present; the presence or absence of the petiole and its length and its attachment to the blade when present; the relation of sessile leaves to the stem; the texture, surface, color, odor, and taste of the leaf; the arrangement of the leaves on the stem; their duration; and their

special modifications of form. Many of these are important also in the functions of plants.

Forms and Kinds.—The more common forms, or outlines, of simple leaf blades are shown in Fig. 9, and the terms used for them are best understood by a study of this figure and its legend. If the leaves of common plants are compared with these figures it will be found that some of them are intermediate between the outlines shown. For instance, a leaf may resemble both the lanceolate and ovate form, and such a leaf may be described by compounding the two terms into such terms as lance-ovate or ovate-lanceolate. Various combinations of the terms given in the legend of this figure may be used in describing leaf blades, and other terms not given here may be necessary in some cases. The forms of many blades are designated by such terms without using special terms for the base and apex, but in some cases the base and apex are of such striking character that special terms are necessary for them. Such characters and the terms used for them are shown in Figs. 9 and 10. The forms of margins are shown in Fig. 9, and the divisions of margins in Fig. 10. A leaf whose blade is all in one piece is called a simple leaf, while one whose blade is divided to the mid-rib is called compound, and its divisions are called leaflets. All of the leaves shown in Fig. 9 are simple, and some compound leaves are shown in Fig. 10. The same terms used for describing simple leaves are used for describing leaflets. The venation of leaves has already been discussed, and is shown in Fig. 9. Stipules have also been discussed, and are shown in Fig. 10. Various lengths of petioles are shown in Fig. 9.

Texture.—The texture of a leaf is often suggested by its appearance, but is more evident by feeling it. No special term is used for the texture of ordinary leaves, such as those of the sweet pea or the lilac. Tough, leathery leaves, such as those of some rhododendrons and laurels, are called coriaceous. Very thin, pliable, and somewhat transparent leaves, such as the submerged leaves of some pondweeds, are called membranaceous. Thick, juicy leaves, such as those of the house leek and the stonecrop, are called succulent.

Surface.—Very striking differences are seen in the character of the surface of the leaves of various plants. Smooth leaves having no hairs on them are called glabrous. The leaves of the dandelion, the lilac, and salal are of this sort. Leaves which are covered with fine, soft hairs are called pubescent. Leaves such as those of mullein, that are covered with a thick coat of entangled hairs, are called woolly. Some leaves, such as those of peppermint and belladonna, have glandular hairs. If these are very abundant, as in petunia and some of the monkey flowers, the leaves are sticky. Leaves that have a whitish coating of powder are called glaucous. The two surfaces of the same leaf may be different, as is illustrated by Labrador tea, whose leaves are glabrous on the upper surface and woolly on the under, and by the hemlock tree whose leaves are glabrous on the upper surface and glaucous on the under. The list of special terms for describing the surface of leaves is rather long, and these may be looked up in a glossary when needed in identifying plants. Hairs on the surface of leaves probably tend in many cases to decrease the evaporation of water, and are thus important from both the functional and the descriptive point of view.

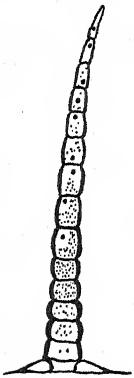

Fig. 16.—A hair from the lower surface of a leaf of wild ginger (*Asarum caudatum*). (Drawn by H. M. Burlage.)

Color.—Though most leaves are green, there are often slight differences in color that are important in description, and in some cases the leaves are of some other color than green. The leaves of one species of beech are copper-colored, and those of the pearly everlasting are whitish. Some leaves, such as those of the Boston ivy, are red when young, but green when mature, while others, such as those of some maples and oaks, are green in summer, but turn red in autumn. The causes of leaf coloration are discussed in Chapter IX.

Odor and Taste.—The odor and taste of some leaves help in the identification of plants. The leaves of the jimson weed have a heavy narcotic odor, and the leaves of many plants of the mustard family have a turnip taste. Many common leaves, however, have no characteristic odor or taste.

Arrangement.—The arrangement of leaves on the stem is often of great use in identifying the plant. If there is only one leaf in a place the arrangement is called spiral, or alternate. Common examples of this are the willows and the alders. If there are two leaves opposite to each other, as in the lilac, the maples, and many mints, the arrangement is called opposite. The place where one or more leaves are borne on a stem is called a node, and if there are three or more leaves at one node, as in the catalpa tree and in bedstraw and some lilies, the arrangement is called whorled. If leaves are in bunches, as in tamarack and pine trees, they are called fascicled.

Duration.—As to the duration, the leaves of shrubs and trees are classified as evergreen and deciduous. The evergreens retain their leaves for a year or more, so that there are always green leaves present, while deciduous trees and shrubs lose their leaves in autumn and their branches are bare in the winter. Evergreen trees and shrubs are conveniently grouped as needle-leaved and broad-leaved. Examples of the former are the pines and the firs, and of the latter are Labrador tea and most rhododendrons and laurels. Needle leaves that are evergreen usually stay on the trees for several years, while broad leaves that are evergreen are, in many plants, shed soon after the new leaves appear, although in some species they remain on the plant two years or more. Many of the common shrubs and trees are deciduous, examples being snowball, lilac, willow, alder, and cottonwood. The fall of the leaf, whether it is evergreen or deciduous, is provided for by a corky layer at the base of the petiole. The fall of the leaf thus reveals a leaf scar (Fig. 17), usually showing the ends of the vascular bundles that penetrated the petiole. The character of the leaf scar is usually characteristic for each species and is often useful in identifying trees in their winter condition.

All of the aërial portions of herbaceous plants usually die down in winter, though in mild climates the leaves of herbaceous plants, such as those of chickweed and cat's ear, may live all winter.

Modified Leaves.—Many leaves are modified so that they have other functions than those of ordinary foliage leaves. In some cases modified leaves still perform foliage functions, and in other cases the modification is so complete that the foliage function is entirely lost. A number of plants have their leaves modified in such a way that they function in securing insect food though still retaining their green color, and thus performing also the functions of ordinary leaves. Such plants are common in peat bogs, marshes, and moist sandy regions in the United States and Canada and are also found in Europe and Asia. One of the commonest of these is the sundew, several species of which are especially abundant in peat bogs. Its leaf blades have large hairs, each with a drop of reddish sticky liquid at its end. Insects are caught in this liquid, and are pressed down on the surface of the leaf by the bending of the hairs. After the digestible parts of the insects have been used the hairs again become erect. The butterwort is found on moist, mossy rocks in northern United States and in Canada and Alaska. Its leaf blades are covered on the upper surface with a greasy substance, and when insects are caught in this the blade folds up on the mid-rib and the insects are digested.

The leaves of the Venus fly trap catch insects by the quickness of their closing. The apical portion of each leaf is composed of two similar parts, one on each side of the midrib, each having a row of stout hairs around its edge and a few sensitive hairs on its upper surface. When an insect touches one of these hairs the leaf closes quickly and the insect is caught and digested.

A number of species of plants belonging to three genera have pitcher-like cavities formed by a portion of the leaf, and are called pitcher plants. Insects entering these pitchers are used as food by the plant. One species common in peat bogs of northern and eastern United States and eastern Canada has its pitchers open at the top and commonly partly

filled with water. Another species (Fig. 149) abundant in peat bogs and bog-like swamps of parts of Oregon and California has its pitchers hooded so that rain does not enter. The pitcher with the hood over its opening presents a somewhat grotesque appearance which may be a factor in causing insects to enter it. Once in, the smooth sides make it almost impossible for them to crawl out.

Several species of insect-catching plants, known as bladderworts, are found in ponds and the shallow margins of lakes in many parts of the United States. They have finely divided leaves, which bear numerous small bladder-like structures functioning as insect traps. Escape of the insects is made difficult by inward-projecting hairs or other obstructions. It is not definitely known that insects are digested in these bladders, but it is known that they are trapped in them.

Several other modifications of leaves enable them to perform functions other than those of ordinary foliage leaves. Some of the leaves of the common barberry have entirely lost their leaf-like appearance and have the form of spines. In the sweet pea and other plants a portion of the leaf is modified into a tendril that enables the plant to climb. Clematis is a climbing plant that lays hold of supports by the bending of the petiole. The leaves of the water hyacinth have an enlarged spongy portion near the base which enables the plant to float. Some leaves, especially those of underground stems, are reduced to mere functionless scales. Examples of these are seen on the underground stems of some mints, and on both the underground and the aërial stems of scouring rushes. In many ferns, such as the bracken and the maiden hair, the foliage leaves bear spores on their lower surface, and in others, such as the rock brake and the deer fern, there are two kinds of leaves, one kind functioning as foliage leaves, and the other mainly in spore-bearing. All of the parts of flowers are modified leaves, and these are discussed in Chapter V.

Suggestions for Further Reading.

The books listed under Chapter I.

CHAPTER III.

STEMS.

THE stem bears leaves and furnishes a channel of communication between the roots and the leaves. In most of our common plants it is above ground and grows somewhat erect. Though there are numerous exceptions, a fairly good idea of the stem as seen in ordinary plants may be conveyed by saying that it is the portion of the plant axis that grows in air, is erect, and bears leaves.

THE ARRANGEMENT OF BUDS, LEAVES, AND BRANCHES.

The leaves of each species are arranged on the stem in a definite system, and the place where one or more leaves are borne is the node, while the portion between two nodes is an internode. The nature of the nodes and internodes often gives a characteristic appearance to the stem, and it may be regarded as a segmented organ. In some stems the nodes are conspicuous because they are thicker than the internodes, and they are sometimes rendered even more conspicuous because a portion of the internode is sheathed by the base of the leaf. Nodes are made conspicuous in this way in corn and other plants of the grass family. In many plants belonging to the buckwheat family the nodes are conspicuously swollen and are sheathed by the stipules. Nodes are also evident in the stems of bedstraw and some prairie lilies because their leaves are borne in whorls. The nodes are also clearly seen in maple trees and other plants having opposite leaves, but are less evident in plants whose leaves are borne singly, as is the case in the willows and the roses.

Since branches grow from buds, and each bud is in the axil of a leaf, the arrangement of the branches is the same

as that of the leaves, and the arrangement of the branches often gives a characteristic appearance to the stem. The three common systems of branching, like the common sys-

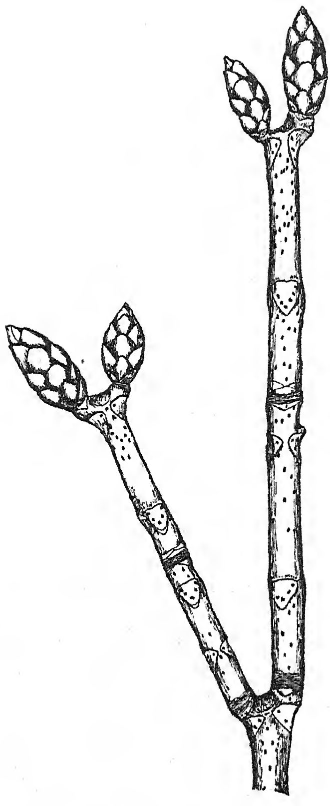

FIG. 17.—A horse-chestnut twig, showing buds, leaf scars, and lenticels. The limit of each year's growth is shown by the scar extending around the stem. (Drawn by M. W. Phifer.)

tems of leaf arrangement, are thus spiral, opposite, and whorled. The spiral, or alternate, arrangement of branches is seen in such trees as willows, alders, apples, and oaks, and such shrubs as the roses, and also in many herbs.

The opposite arrangement of branches is seen in such trees as the maples and the dogwoods, and such shrubs as the elders, the lilacs, and the high-bush cranberry, and is also seen in some of the herbaceous speedwells (*Veronica*). In the maples the opposite branching is evident on the younger portions of the trees, but may be less conspicuous on older portions because one branch of a pair may fail to develop. The opposite arrangement of branches in dogwood trees is also somewhat obscured on older stems and main branches partly because some branches fail to develop and partly because many of the internodes are so short that two or even more pairs of branches are borne close together giving them a somewhat whorled appearance.

Whorled branching is less common than the other two systems. Catalpa trees often have three leaves in a whorl, but because of the failure of some buds to develop the branching usually appears to be alternate. Whorled branching is seen in the main branches on the young trunks of some species of pine and to some extent in the smaller branches on these main ones. Douglas fir also has a tendency to whorled branching on the main stem, especially in young trees. This arrangement of branches is conspicuous in the monkey-puzzle tree (*Araucaria*), a South American tree now commonly cultivated and often seen on lawns and in botanical gardens. The whorled arrangement of branches on the trunk is quite perfect, but the smaller branches on these main ones are usually opposite.

GROWTH HABITS OF STEMS.

Though the stems of most common plants grow in air and are known as aërial stems, there are some (*e. g.*, the pondweeds and waterweeds) that are entirely submerged, and others, such as those of the common ferns, that grow entirely underground. There are also some plants (*e. g.*, Solomon's seal) that have a perennial underground stem and an annual aërial stem. Though the stems of most of our common plants grow erect, there are many that do not. Some stems, such as those of the watermelon and the trailing arbutus, lie flat

on the ground, and there are many gradations between this and the erect position. The stems of some blackberries, for instance, tend to grow erect but are too weak to stand when they grow to any considerable length. The stems of many plants climb on the stems of other plants or on supports of other kinds. The sweet pea and the passion flower climb by tendrils, several species of clematis climb by twisting their petioles around supports, the ivy and the trumpet creeper climb by aërial rootlets, and the morning glory and the hop climb by coiling spirally around other stems or around supports of other kinds.

In some trees the terminal bud grows vigorously, and this produces a strong central stem, as in the pines and the firs, while in other trees, such as the maples and the willows, the lateral buds are relatively vigorous and the tree has a diffuse form, the branches being more conspicuous than the stem in the upper portion of the tree.

The form of a tree may be changed, however, by shading, and maples and some other trees develop strong, straight trunks with few branches, except at the top, where they grow in close stands. Pines and firs produce many branches when they grow singly, though the central stem still grows straight. Shrubs (*e. g.*, the snowball and the lilac) tend to produce several stems from the base.

STEM TISSUES.

The different functions of stems are performed by various somewhat specialized tissues. The conduction of water and dissolved substances from roots to leaves, and the conduction of some of the dissolved foods from leaves to other points in the plant, where they are either used or stored, is performed largely by the vascular bundles, and these bundles also play a large part in the mechanical function of support. Many stems also contain other mechanical tissues, such as the sclerenchyma common in perennial stems and the collenchyma of both herbaceous and perennial stems. Some store considerable quantities of food, and certain tissues, mainly parenchyma, function in this way. Parenchyma also func-

tions to a certain extent in the conduction of dissolved materials. Corky tissues at the surface serve for protection, especially against excessive loss of water. The growth of stems in both length and thickness takes place from meristematic tissue.

MONOCOT STEMS.

Four classes of plants—monocots, dicots, gymnosperms, and ferns—have vascular bundles, and are thus stem-producing plants, commonly spoken of as vascular plants, to distinguish them from the lower plants, such as mosses, liverworts, and algæ, which do not have vascular tissues. The word fern as used here includes not only the common ferns, but also their relatives, such as the scouring rushes, the club mosses, and the quillworts. The essential features of the structure of the stems of this group may be shown, however, by describing the stems of the common ferns. Since the coniferous trees are the most common and abundant of the gymnosperms, their stems will be discussed in this chapter rather than those of the larger group.

The structure of monocot stems may be illustrated by describing the stem of corn. The outer portion of this stem consists of hard sclerenchyma several cells in thickness, covered at the outside by an epidermis one cell in thickness. The interior is composed of soft parenchyma (the pith) traversed lengthwise by vascular bundles. The layer of sclerenchyma is a part of the cortex, and the rest of the cortex is composed of the parenchyma cells lying next to the sclerenchyma. In this stem there is no sharp line between the cortex and the vascular cylinder (stele).

If a cut is made across an internode (Fig. 18) of this stem, three regions are easily seen. The hardness of the sclerenchyma and the softness of the parenchyma is evident by testing them with a dissecting needle or the point of a knife, and the vascular bundles are seen as separate dots scattered through the parenchyma. In a longitudinal section of the internode the sclerenchyma and parenchyma are seen as in cross-section, while the vascular bundles appear as fibers, extending lengthwise through the stem and may be readily

dissected out. These separate vascular bundles have many intercommunications, so that one bundle cannot be traced throughout the whole length of the stem. This condition is especially evident at the nodes, where the intercommunications are very numerous. It is the vascular system that is continuous through the stem rather than the individual bundles. At each node some of the bundles extend into the leaf.

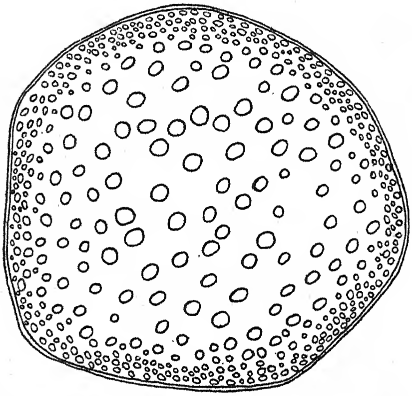

FIG. 18.—Diagrammatic cross-section of an internode of corn stem. The sclerenchyma is shown at the surface. The circles show distribution and relative size of the vascular bundles. The remaining portion represents parenchyma. (Drawn by M. W. Phifer.)

In a thin cross-section of an internode of this stem viewed under a microscope the cells of the sclerenchyma are seen to be thick-walled, while those of the parenchyma are thin-walled and larger. If a phloroglucin solution is applied, followed by hydrochloric acid, the walls of the sclerenchyma cells become red after a few minutes, while those of the parenchyma do not. This indicates that the walls of the sclerenchyma cells are lignified, while those of the parenchyma are not. In permanent mounts, where two stains have been used, these two tissues will usually be clearly differentiated, not only by the difference in the character of the cells but also because they will be of different color. In the longitudinal section the cells of these two tissues may

show slight elongation in the direction of the length of the stem, but otherwise their appearance is not conspicuously different from that seen in the cross-section.

The vascular system of stems and roots functions in the translocation of water and dissolved materials. A vascular bundle is composed of two regions—the xylem and the phloem (Fig. 19). The xylem functions mainly in the conduction of water and dissolved materials from the roots to the leaves and growing regions, while the phloem functions mainly in the conduction of dissolved organic materials from leaves and other regions where foods are formed to regions of storage, such as roots and underground stems, and to growing points where these materials are being used. Although there are many exceptions, the main movement of materials in xylem is upward in the stem, while the main movement in phloem is downward.

The xylem in monocots is composed mainly of vessels and the cells that lie between them. There are some tracheids present, but they are less conspicuous than the vessels, and they perform comparatively little of the conduction; and their function as mechanical fibers is more important. A vessel is composed of cells set end-to-end whose living material and end walls have disappeared, thus forming a tube. These tubes are not continuous through the entire length of the stem, and the water in its upward movement through the vessels must at many points move through a cell wall. A tracheid consists of a single cell whose living material has disappeared and whose walls are marked by thin places, frequently in the form of round pits, and the movement of water from tracheid to tracheid is mainly through these pits. In the main, vessels are characteristic of monocots and dicots, while tracheids are characteristic of gymnosperms and ferns, and will be discussed more fully in connection with those stems.

In a cross-section of a bundle of corn (Fig. 19) seen under the microscope the xylem is readily identified by the fact that the vessels are large and conspicuous. There are usually four vessels—two large ones, a little distance apart, but both lying next to the phloem, and two smaller ones in

contact with each other and situated a little distance from the phloem. There is usually an open "air space" next to the two small vessels on the side away from the phloem. The space within the wall of a dead cell is called the lumen,

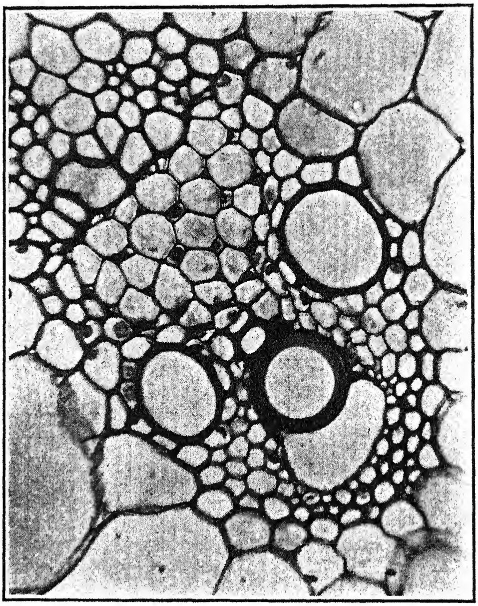

FIG. 19.—Cross-section of a vascular bundle of corn stem. Three large vessels are shown, each with thick wall and large lumen. Just above the central one is a smaller vessel, and just below it is an irregular air space. The vessels and the cells lying between them (some of which are tracheids) constitute the xylem. The phloem lies just above the xylem and consists of large sieve tubes with thin, straight walls, and small companion cells at the corners of the sieve tubes. Thick-walled fiber cells (often termed bast) are shown at the outside of the bundle, and outside these are the pith parenchyma cells. (Photomicrograph by H. B. Gray.)

and in this section the vessels are seen to be composed of wall and lumen only. The walls of the vessels are lignified, as may be seen by applying the phloroglucin-hydrochloric acid test. The tracheids of a corn bundle are small, thick-

walled cells lying next to the small vessels between the large ones.

The phloem (Fig. 19) consists of sieve cells and companion cells. The former are larger, and both are somewhat squarish in cross-section. They are arranged in a rather definite pattern, a companion cell being at each place where four sieve cells come together. The material within the cell wall usually does not show in the sieve tubes but does show in the companion cells. Some of the sieve cells in a cross-section may be cut through the end wall, and this wall will then appear as a somewhat porous structure closing the cell. Sclerenchyma fibers usually lie between the bundle and the surrounding parenchyma, enclosing the bundle (Fig. 19). The corn bundle is called collateral, since the xylem and phloem lie side by side, and is called closed since it has no cambium and is thus not capable of secondary thickening. Secondary thickening is characteristic of dicots and gymnosperms, and will be discussed in connection with the stems of these groups.

The xylem is conspicuous in longitudinal sections of corn stem. The section shown in Fig. 20 is cut in such a way as to pass through one of the large vessels and one of the smaller ones. The portion of a vessel developed from one cell is called a vessel segment. One complete segment and portions of two others are shown in the larger vessel in this figure. Its walls show conspicuous pits, and it is of the kind called pitted vessels. The smaller vessel shows conspicuous ring-like thickenings and is of the kind termed annular vessels.

The character of the phloem is not readily seen in longitudinal sections of corn stems, but is easily seen in sections of the stem of pumpkin (a dicot). Sieve tubes are important elements in phloem. In the type of sieve tube common in monocots and dicots (Fig. 20) the sieve cells have tranverse end walls. These walls are perforated, and the cytoplasm is continuous from cell to cell through these perforations. One sieve cell and portions of two adjacent ones are shown in Fig. 20. In monocots and dicots the sieve tubes are accompanied by companion cells, and these show nuclei while the sieve cells do not.

While the stem of corn gives a fairly good general idea of the structure of monocot stems, many monocot stems show considerable differences from it. The stems of many monocot herbs, such as the trilliums, are much softer and weaker, and have relatively few bundles and little mechanical tissue. In wheat and most of the common grasses the internodes are

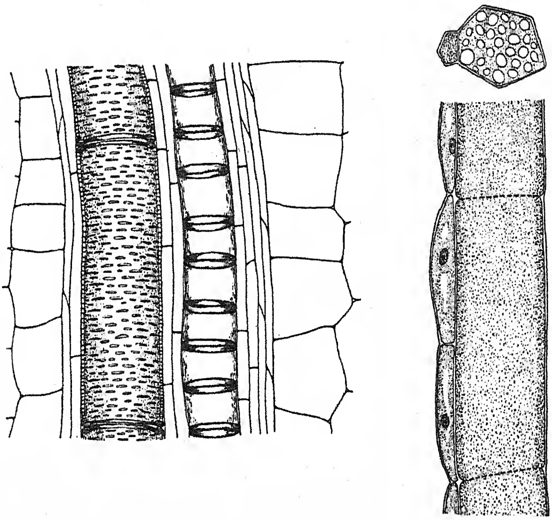

Fig. 20.—The structure of xylem and phloem. Left, a longitudinal section through the xylem of a vascular bundle of corn, showing a pitted vessel (left) and an annular vessel (right). One row of large parenchyma cells is shown at each side of the figure. Some fiber cells (with diagonal end walls) are shown next to these parenchyma cells. Right, longitudinal section (semi-diagrammatic) of a sieve tube and companion cells of a pumpkin stem. The sieve tube is broad and shows no nuclei. The companion cells are narrow and show nuclei. At the top is a longitudinal section, showing a sieve plate with its perforations and a section through a companion cell. (Drawn by M. W. Phifer.)

hollow, the bundles are crowded close to the outside, the sclerenchyma of the cortex is relatively thick and hard, and the stem is thus light but strong. Several perennial woody monocot stems, such as those of *Aloe,* have cambium and show secondary thickening, though this is of a different type from that found in dicots.

Although the vascular bundles commonly seen in monocots are collateral, concentric ones are also found. These have the xylem surrounding the phloem and are called amphivasal to distinguish them from the amphicribral bundles of ferns, in which the phloem surrounds the xylem. The collateral type is commonly the only one present in annual monocot stems, but amphivasal bundles are present in many perennial underground monocot stems and in the nodes of many annual aërial stems arising from these. Such bundles are characteristic of the rhizomes of the sweet flag and of both the rhizomes and the nodal regions of the aërial stems of many grasses and sedges.

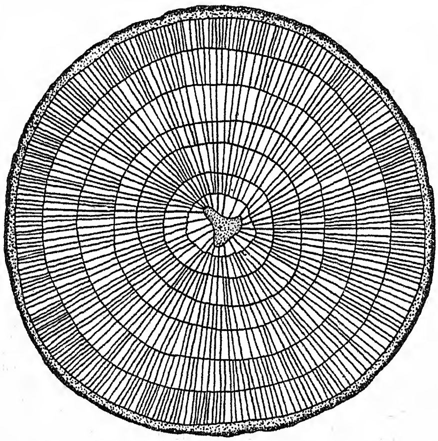

FIG. 21.—Diagrammatic cross-section of a young alder stem, showing pith, wood, and bark. Annual rings and wood rays are shown in the wood. (Drawn by M. W. Phifer.)

DICOT STEMS.

A woody dicot stem, such as that of willow, maple, or alder, shows three regions—pith, wood, and bark. These may be readily seen with the unaided eye in either a cross-section (Fig. 21) or a median longitudinal section. In the cross-section the wood is seen to be made up of annual rings with wood rays extending inward from the outer surface of

the wood, some continuous to the pith and others extending only part of the way to it. Phloem rays are usually found in the bark, but it is not easy to see them there without the aid of a compound microscope. The annual rings and the wood rays can also be made out fairly well in a median longitudinal section, cut smooth with a sharp knife.

The wood is composed of xylem, while the bark of a mature stem is composed mainly of phloem. Between the two is the cambium (Fig. 27), a meristematic tissue whose cells divide, the outer ones differentiating and forming the various tissues of the phloem, while the inner ones differentiate and form the various cells of the wood. Some of the cambium cells, of course, remain meristematic and continue the existence of the tissue, while others give rise to the wood and bark. The cambium is a thin cylinder of tissue and is seen only with the aid of the microscope.

In a cross-section viewed under the microscope the nature of the annual rings is more plainly seen (Fig. 22). The line at which each year's growth ceased and the next year's growth began is plainly marked, and some differences between the cells formed in the early part of the season and those formed in the latter part can usually be seen. The spring cells are usually a little larger than the summer cells and their walls a little thinner.

Vessels are plainly seen in such a section, each one showing a thick lignified wall and a large lumen. In some woods, such as oak (Fig. 22) the vessels in the spring wood are much larger than those in the summer wood. Such wood is spoken of as being ring-porous to distinguish it from others in which the vessels are more uniformly distributed through each annual ring. Vessels are characteristic of most dicots, though they are absent in some, even in a few woody ones. Some parenchyma is found in the wood of most woody dicots. Numerous wood rays are seen extending across each annual ring, and continuous from one annual ring to another. In oak wood (Fig. 22) the ordinary rays are one cell in thickness, and occasional larger rays many cells in thickness are seen.

A small amount of primary xylem is found next to the pith in woody dicot stems. This is formed from the meristem in

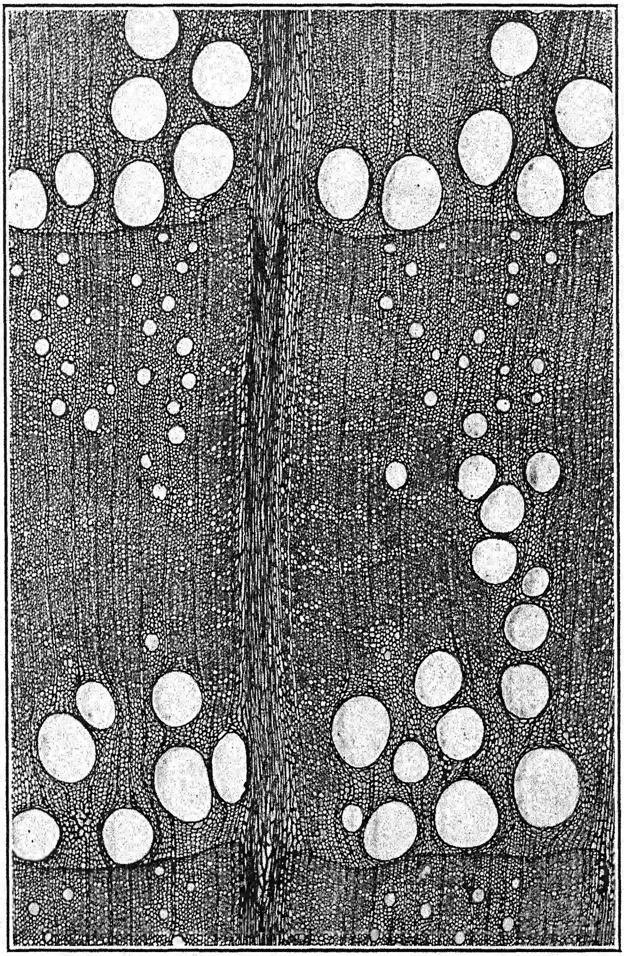

FIG. 22.—Photomicrograph of cross-section of oak wood, showing entire width of one annual ring and portions of two others. Wood rays extend across the annual rings; one large compound one in the middle of the field and numerous narrow simple ones elsewhere. The circles (except the very minute ones) represent vessels. The very minute circles appearing in bands mark the wood parenchyma, each circle representing a cell. The large, thin-walled cells around the vessels in the spring wood are tracheids. (Courtesy U. S. Forest Products Laboratory.)

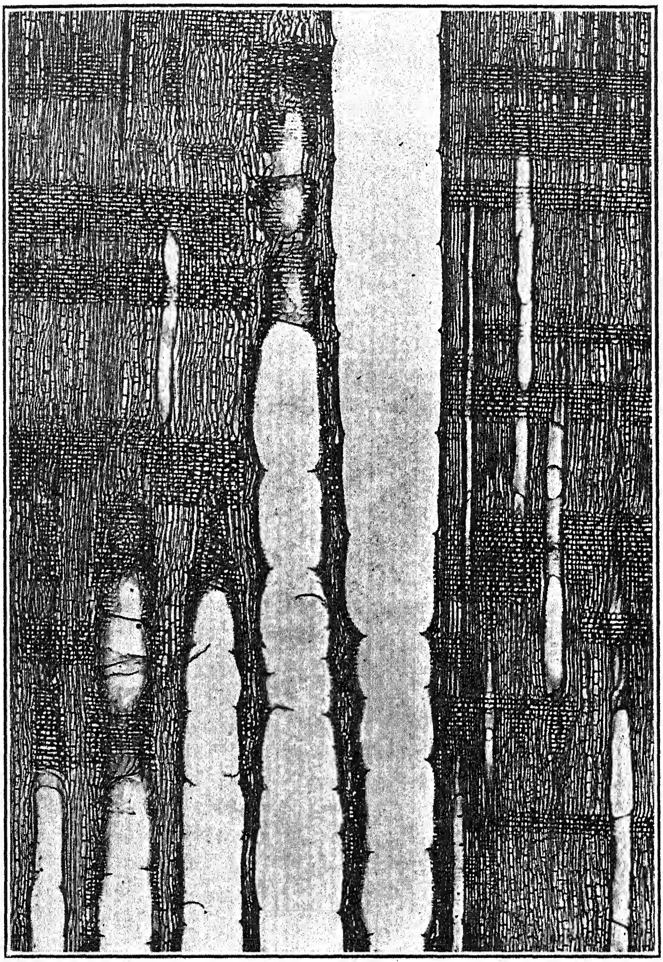

FIG. 23.—Photomicrograph of radial section of oak wood. The large open space extending from top to bottom of the figure represents a vessel, and other vessels extend part way through the figure. The lines projecting slightly into the vessels show the points where the ends of the cells fused in forming the vessels. Some tracheids are shown at the top of the figure just at the left of the large vessel. The wood fibers extend in the same direction as the vessels, and some parenchyma is shown among them. Wood rays extend across the figure at right angles to the wood fibers. (Courtesy U. S. Forest Products Laboratory.)

the stem tip, and does not show the radial arrangement seen in the secondary xylem formed from the cambium.

A radial section is a longitudinal section cut in a plane extending from the circumference directly toward the center of the stem. In such a section of a woody dicot stem the wood fibers, wood parenchyma, wood rays, and vessels are seen. In a radial section of oak wood (Fig. 23) the vessels are large and conspicuous, one of them extending entirely through the section. The others extend through only a part of the section, since it was not cut exactly in line with them. Since most of the vessels in this section are cut through the center, the markings on their walls are not shown, and each vessel appears as a vacant space. An entire vessel segment (the portion formed from one cell) of magnolia wood is shown in Fig. 25, and it shows the markings on the wall clearly.

In the radial section the wood rays are seen extending across the vessels and wood fibers at a right angle, each ray being several cells in height. Much of the wood in a woody dicot is made up of wood fibers, which are elongated cells extending lengthwise of the stem. These and some parenchyma are seen in the radial section of oak wood (Fig. 23).

A tangential section is a longitudinal section cut at a right angle to the radial section, and is thus cut at a tangent to the annual rings. In such a section (Fig. 24) the wood fibers and the vessels are cut lengthwise and the wood rays are cut crosswise. The vessels and the wood fibers show much the same appearance as in the radial section. Oak wood shows many small wood rays one cell in thickness and several cells in height and occasional enormous rays many cells in thickness and height. One of these enormous rays and several of the ordinary ones are shown in Fig. 24.

In the development of wood from the meristem at the stem tip the primary wood commonly forms a cylinder at a very early stage, but in some stems, such as that of the birthwort (*Aristolochia*), shown in Figs. 29 and 30, the first bundles are separate and the complete cylinder is formed later when secondary growth forms annual rings. In this stem the bundles are separated by bands of parenchyma (Fig. 30).

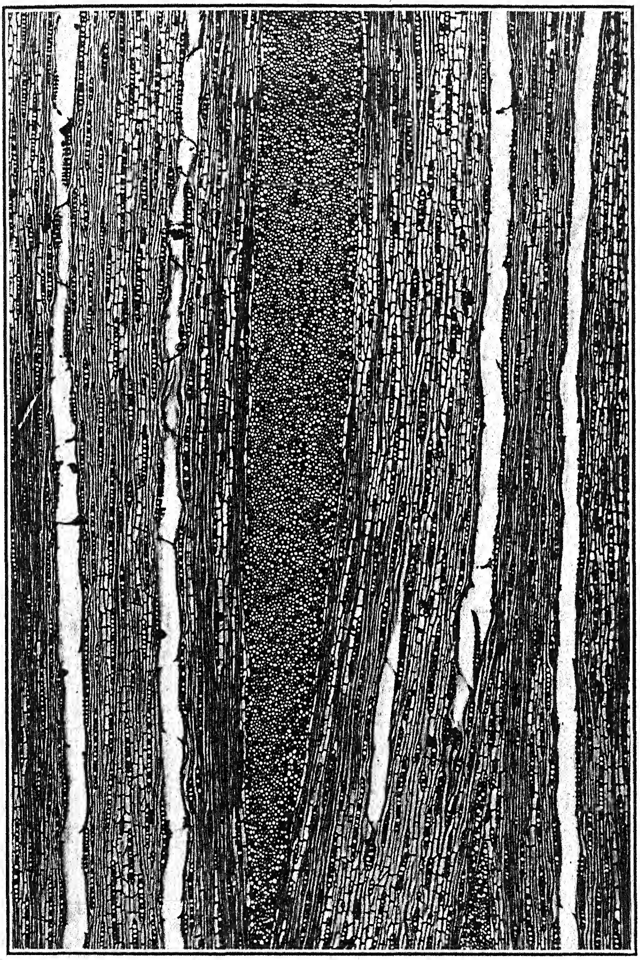

Fig. 24.—Photomicrograph of tangential section of oak wood. Vessels are seen as in the radial section (Fig. 23). Cross-sections of the wood rays are seen; a very large compound one extends from top to bottom in the middle of the figure, and numerous simple ones one cell in width are seen elsewhere. Wood fibers and parenchyma are seen as in the radial section (Fig. 23). (Courtesy U. S. Forest Products Laboratory.)

The pith in a mature woody dicot stem is relatively small, and is composed of dead parenchyma cells. Old dicot trees may become hollow by the decay of the pith and the heart wood, while the sap wood continues sound.

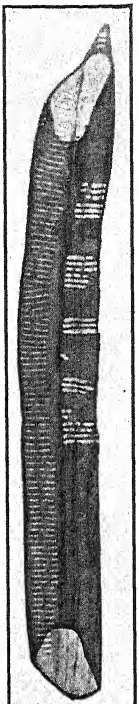

FIG. 25.—A vessel segment (the portion developed from one cell) of magnolia wood. The pits are elongated and extend across the vessel. (Photomicrograph by W. M. Harlow.)

Bark.—The bark consists of all of the tissues outside of the cambium. It is readily stripped off from the younger branches of such trees as willows and alders, and in all common trees and shrubs it is distinctly different from the wood in texture and general appearance. In woody dicots it is composed of sieve tubes, parenchyma, phloem rays, bast, stone cells, and cork. Fig. 26 shows a cross-section of the bark and a portion of the wood of ash. The cork, the stone cells, the phloem rays, and the layers of bast are conspicuous in this section. The cork forms a thick layer at the outside of the bark (the top of this figure) and some of the layers of the cork cambium from which it is formed are also seen. One of these is the irregular dark line extending nearly across the figure. Cork is composed of dead cells whose cell walls contain a fat-like constituent which renders the tissue impervious to water, and thus protects the tissues beneath from excessive loss of water, and also prevents water from entering from the surface and thus bringing in organisms which would cause decay. It also functions to a certain extent as a protective mechanical tissue.

All of the tissues present in old bark except the cork arise directly or indirectly from the cambium which lies between the wood and the bark, but the cork is formed from a special meristematic tissue, the cork cambium (phellogen), which originates from the cells of the cortex, the epidermis, or the

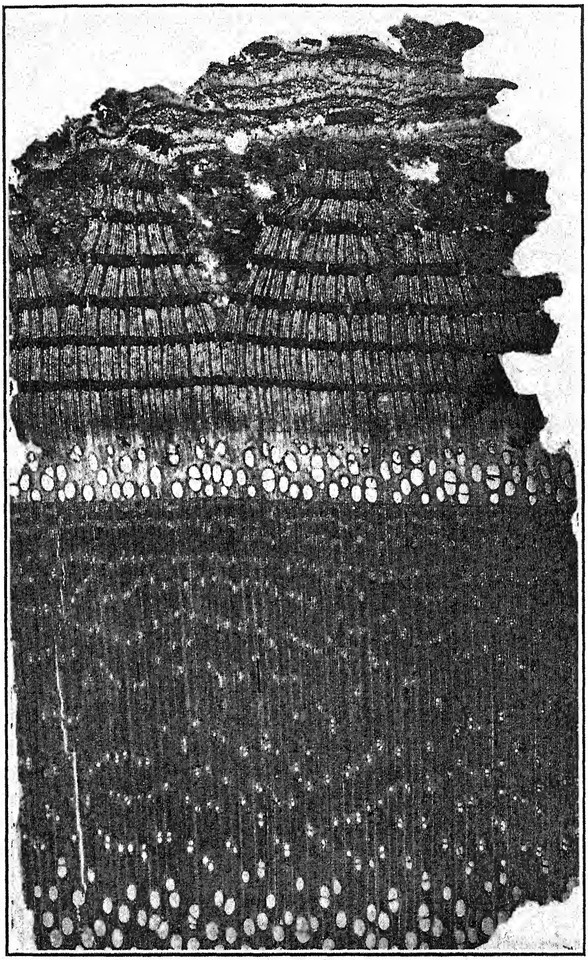

FIG. 26.—Photomicrograph of bark (at top) and portion of wood of ash. The dark bands extending across the figure show the bast of the bark, and the phloem rays extend at right angles to these. Three large irregular masses of stone cells interrupt the outer bands of best. Cork and cork cambium appear at the top of the figure. The thin-walled cells between the rows of bast are sieve tubes, companion cells, and phloem parenchyma. (Courtesy U. S. Forest Products Laboratory.)

phloem. The ordinary cambium is a primary meristem since it arises from the meristem at the growing tip of the stem, while the cork cambium is a secondary meristem since it is formed from tissues other than the apical meristem, frequently from the cells of tissues that are more or less permanent. Cork cambium, by continued divisions of its cells, forms the cork, and since it usually forms cork from its inner surface as well as from its outer, it is eventually sloughed off and new layers of it are formed farther in.

Young bark has an epidermis and a cortex formed from the meristem at the tip of the stem, and these may increase in extent by cell division, but are eventually sloughed off in perennial woody plants by the increase in the thickness of the stem and the growth of the cork beneath them, so that the cork forms the outer layers of the bark.

Phloem rays are formed from the cambium which lies between the wood and bark, and they extend outward into the bark. In the bark of some trees and shrubs the phloem rays are rather irregular and are plainly seen in only the inner portion, but in the ash (Fig. 26) they appear in the cross-section as rather regular narrow lines extending from the cambium to the cork. The layers of bast in this figure are the broader, dark bands extending at right angles to the phloem rays. Two conspicuous masses of stone cells are shown toward the right side of the figure, just beneath the cork and interrupting the layers of bast. Bast cells and stone cells are dead cells with thick, lignified walls, and small lumen, and their function is mechanical. Bast cells are usually elongated in the direction of the length of the stem, and are thus more or less fiber-like. The toughness of the bark of some plants, such as that of leatherwood, which was used for thongs by the Indians, is due to the fibrous character of the bast. Stone cells are either somewhat rounded or are very irregular in shape, and give hardness rather than toughness to bark. Fig. 36 shows a very irregular stone cell from the bark of a conifer.

Crystals are often present in bark as well as in other portions of plants. Fig. 28 shows them in the bark of a dicot tree. Many of the crystals in plants are composed of cal-

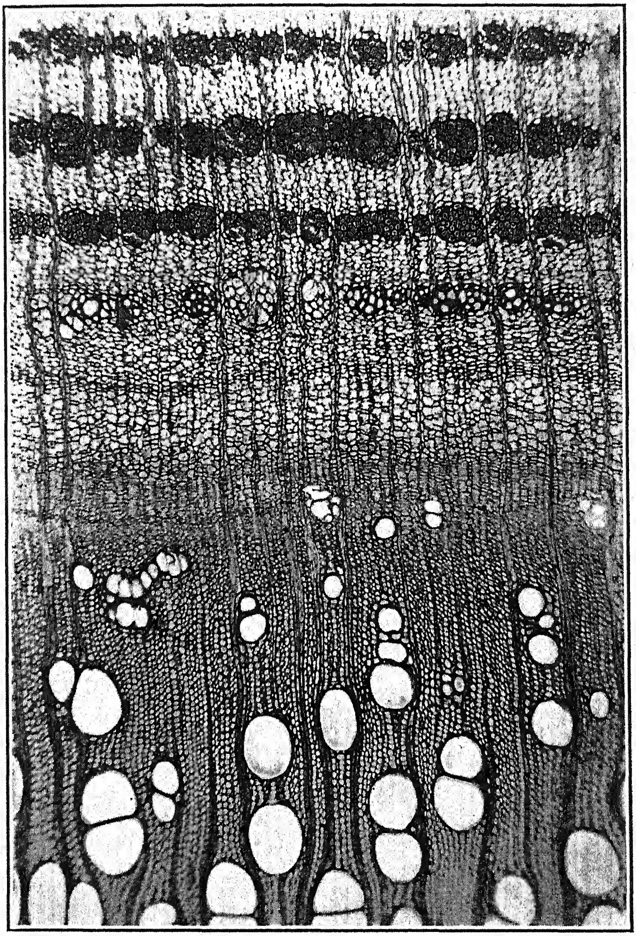

FIG. 27.—Active cambium and portion of wood and bark of ash. The cambium cells are small, and lie side by side in radial rows between the wood and the bark. Compare Fig. 26 for the general structure of bark and Fig. 22 for the general structure of wood. (Photomicrograph by E. S. Harrar.)

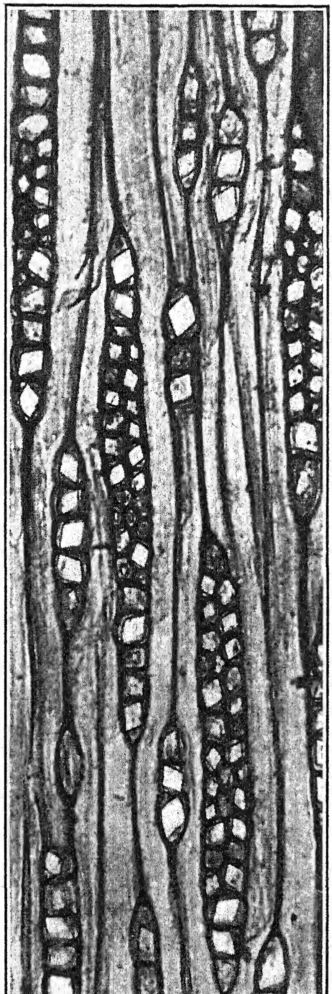

FIG. 28.—Crystals in phloem rays in a tangential section of bark of ironwood (*Ostrya virginiana*). (Photomicrograph by E. S. Harrar.)

cium oxalate, but some of them are possibly composed of other substances. Calcium oxalate is so slightly soluble in water that its presence can have but little influence on the metabolism of the plant. Oxalic acid is a poisonous substance and is common in plants. Possibly the formation of crystals of calcium oxalate is thus a benefit to plants, since it is accomplished by the conversion of a poisonous substance into a harmless form.

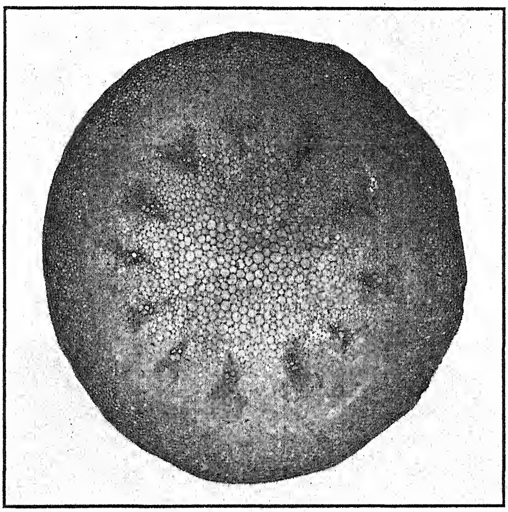

Fig. 29.—Cross-section of young stem of birthwort (*Aristolochia*), showing separate vascular bundles. Pith is shown inside the circle of bundles and cortex without. (Photomicrograph by G. H. Needham.)

Small spots called lenticels (Fig. 17) occur on the twigs of most woody plants. These are areas where the continuity of the cork is interrupted by the formation of a mass of loosely arranged cells, and gases can diffuse in and out through the intercellular spaces thus formed. They usually originate under stomates, when the formation of cork begins.

The outer layers of the bark are commonly shed as the stem grows older. This occurs in various ways. In some plants it is shed as scales and in others in strips or in other

ways. In some birch trees papery layers peel off around the the trunk. In some trees, such as the sycamore and the madrona, a thin layer of bark is shed each year.

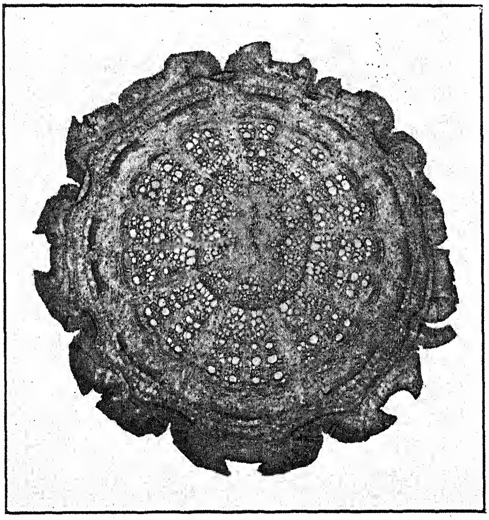

FIG. 30.—Cross-section of stem of birthwort (*Aristolochia*) several years old, showing annual rings formed by the xylem. Broad rays formed by the cambium lie between the portions of the xylem. A thick layer of cork lies at the outside of the stem. (Photomicrograph by G. H. Needham.)

Herbaceous Dicot Stems.—The stems of herbaceous dicots differ in some ways from those of woody dicots. Woody dicot stems are, of course, perennial, and their cambium resumes activity in many successive growing seasons, while herbaceous dicot stems are annual, and the activity of the cambium is confined to a single season. Stems which are ordinarily annual may, however, become somewhat woody and endure for more than one season in very mild climates. A plant whose aërial portions are annual may, as elsewhere mentioned, have perennial underground portions.

It is impossible to state any exact distinctions between herbaceous dicot stems and woody ones up to the end of their

first year of growth. They are similar in that they may retain their epidermis, have a relatively large amount of cortex and pith, and have considerable chlorenchyma. In some herbaceous stems, however (*e. g.*, buttercups), the vascular bundles do not form a continuous cylinder, but are separated by rather broad bands of parenchyma which are continuous with both the pith and the cortex. This is not a distinctive feature of herbaceous stems, since such bands occur in woody vines, such as *Clematis* and also in perennial stems that are not vines (*e. g.*, *Berberis*). This type of stem is also seen in the twining shrub, *Aristolochia* (Figs. 29 and 30). These bands are continuous from node to node, and are thus quite different from the wood rays of such stems as alder and oak (Fig. 24). A herbaceous stem (*e. g.*, clover) may have separate bundles in the upper portion and a woody cylinder in the lower portion.

We can thus separate two types of dicot stems, one having separate vascular bundles with broad bands of parenchyma between them, extending from node to node, and the other having a cylinder of wood with wood rays which are not continuous from one node to another. The first type, however, includes many woody vines and some woody perennial stems that are not vines. It is generally believed that the type with separate bundles has been evolved from the woody type by the breaking-up of the vascular cylinder into separate portions.

The bundles of dicots, like those of monocots, have the xylem and phloem side by side and are thus collateral. They differ from those of the monocots, however, in having cambium. In the stems of pumpkin and squash and other members of the gourd family the bundles are separate and are of the bicollateral type with two phloem strands—one on the inner side of the xylem and one on the outer.

CONIFEROUS STEMS.

Coniferous stems, such as those of pines, firs, spruces, hemlocks, and cedars are similar to those of woody dicots in their gross anatomy, but differ considerably from them

in microscopic structure. Coniferous stems (Fig. 31) show wood, pith, and bark, just as woody dicots do, and the wood shows annual rings and wood rays.

Coniferous wood, however, differs from dicot wood in microscopic structure. Vessels are characteristic of dicot stems, but are absent in the secondary wood of coniferous stems, and most coniferous wood consists largely of fiber tracheids. A tracheid is a single elongated cell, usually

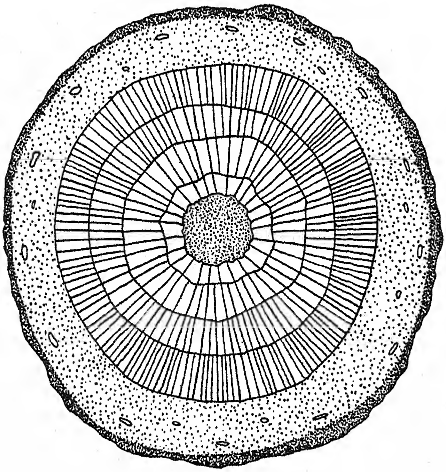

FIG. 31.—Diagrammatic cross-section of a young Douglas fir stem, showing pith, wood, and bark. Annual rings and wood rays appear in the wood. Resin canals are seen in the bark. The darkened outer portion of the bark is the cork. (Drawn by M. W. Phifer.)

tapering at both ends, and at maturity consists simply of the lignified wall and the lumen. In Douglas fir wood practically all of the fibers are tracheids, and they are about $\frac{1}{6}$ inch long. In white pine they are about $\frac{1}{8}$ inch long, and in hemlock they are much shorter. The tracheids of conifers have bordered pits (Fig. 35) in their walls. In the mature wood of many conifers these pits occur only in the tangential walls of the tracheids, and are thus seen best in the radial section. Bordered pits do occur in dicot and monocot stems,

but they are most abundant in coniferous stems and are characteristic of them.

A bordered pit (Fig. 35) consists of a circular opening in the wall of the tracheid and a corresponding opening of the same size and shape in the wall of the adjacent tracheid, with a membrane between the two openings. This membrane has a thickened disk in its center, opposite the openings in the tracheid walls, and the tracheid walls around the opening flare a little so that they stand out from the membrane. The flaring walls thus form a circle around the pit constituting its border, and the bordered pit thus consists of the circular opening and the flaring walls, with the membrane forming a partition between the two openings. When viewed from the side (radial section) under the microscope the pit and its border are readily recognized. In a tangential section, and also in a cross-section of a coniferous stem, the bordered pits are seen in cross-section. The thin portion of the membrane lying between the flaring portions of the walls is rather readily penetrated by water, and since there are many bordered pits in the walls of two adjacent tracheids the movement of water through the stem is comparatively well provided for.

Resin canals are quite characteristic of coniferous stems, but they are less common in dicot stems. They are, however, found in a number of woody dicots (*e. g.*, mahogany). They are mostly intercellular spaces formed by the separation of the cells during the growth of the stem. In the Douglas fir they extend lengthwise through the bark (Fig. 31) and the wood (Fig. 32), and occasionally one is found extending crosswise of the stem in a wood ray (Fig. 34). They are also common in pines, larches, and spruces.

In some conifers, such as Douglas fir (Fig. 32), yellow pine, and others, there is a great difference between the spring cells and the summer cells, the former having thin walls and large lumen, while the latter have thick walls and small lumen. In such cases the grain of the wood is conspicuous. In most coniferous stems the wood rays (Fig. 34) are only one cell in width, but vary greatly in height.

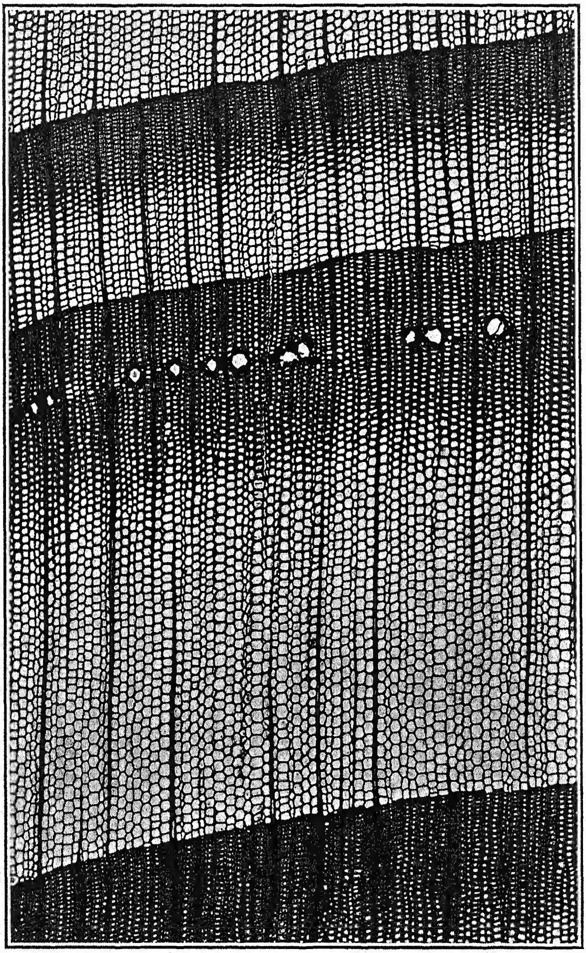

FIG. 32.—Photomicrograph of cross-section of Douglas fir wood, showing the full width of two annual rings and portions of two others. The spring cells (fiber tracheids) appear at the bottom of each annual ring and the summer cells (also fiber tracheids) at the top. Wood rays extend across the annual rings. Resin canals are shown in the summer wood of one ring. (Courtesy U. S. Forest Products Laboratory.)

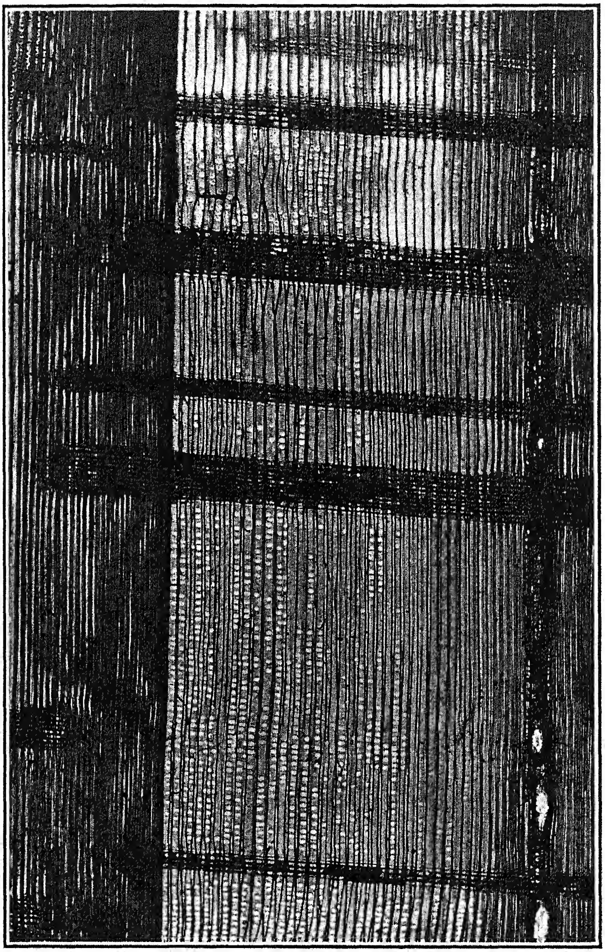

FIG. 33.—Photomicrograph of radial section of Douglas fir wood. Summer cells (fiber tracheids) are shown at the left, and spring cells (also fiber tracheids) of the succeeding annual ring at the right of these. Bordered pits (Fig. 35) are shown in the spring tracheids. A resin canal extends from top to bottom of the right side of the figure. Wood rays extend across the fiber tracheids. (Courtesy U. S. Forest Products Laboratory.)

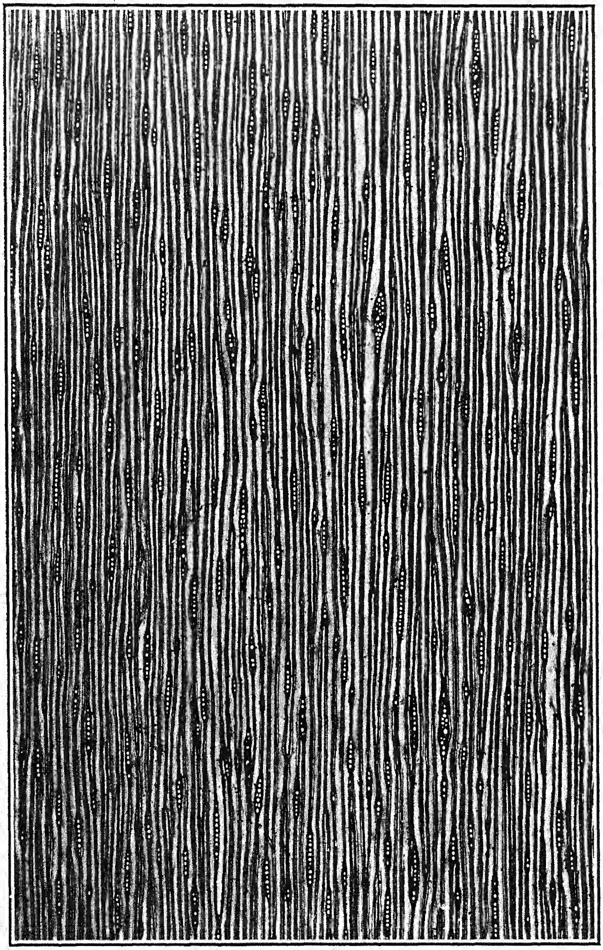

FIG. 34.—Photomicrograph of tangential section of Douglas fir wood. Fiber tracheids extend up and down in the figure. Wood rays, seen in cross-section, lie among these. A few fusiform rays, each with a resin canal in its center, are seen toward the right side of the figure. (Courtesy U. S. Forest Products Laboratory.)

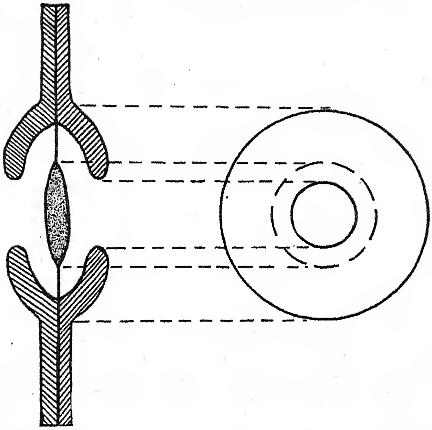

FIG. 35.—A bordered pit of Douglas fir. Cross-section at left; surface view at right, with the corresponding portions indicated by broken lines. The cross-hatched portions represent the walls of two adjacent fiber tracheids, and the line between them, the middle lamella. The thickened disk (torus) is characteristic of these pits. (Drawn by M. W. Phifer.)

FIG. 36.—A stone cell from hemlock bark. (Photomicrograph by E. S. Harrar.)

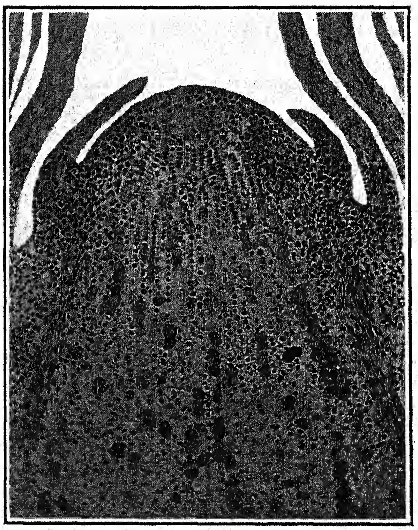

FIG. 37.—Longitudinal section of the growing point of a pine stem, showing meristem. The beginning of the formation of primary wood is seen near each side of the figure a little back from the meristem. (Photomicrograph by W. M. Harlow.)

FERN STEMS.

The stems of the common ferns are generally underground structures; the aërial portion of the plant usually consists wholly of one or more leaves. Fern stems have a cortex, which is usually rather thick, and a central stele composed of vascular bundles variously arranged. The bundles have no cambium, and are thus incapable of secondary thickening. The structure of fern stems is described in Chapter XVII.

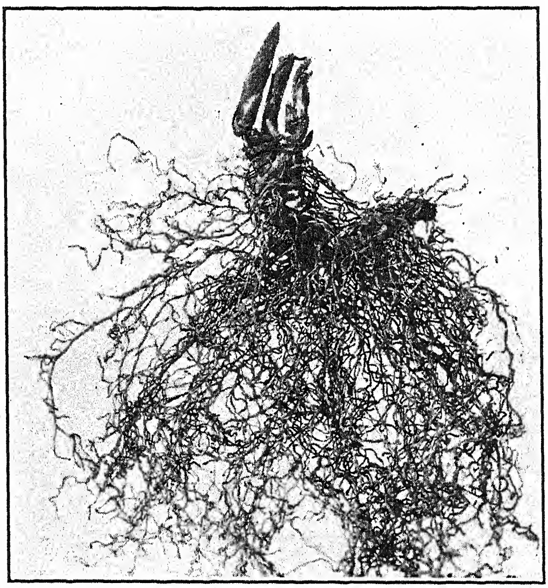

FIG. 38.—Rhizome and roots of blue cohosh (*Caulophyllum*).

UNDERGROUND STEMS.

Underground stems are common in monocots, dicots, and ferns. They are of three principal kinds—rhizomes, tubers, and bulbs. Rhizomes are common in all three groups, but tubers are most common in dicots, and bulbs are most commonly formed by monocots. Rhizomes (Fig. 113) are somewhat elongated, and usually, though not always, have a

horizontal position. They may be very slender, as in quack grass, or very thick, as in the water lily. Rhizomes are characteristic of perennial plants, as is illustrated by many grasses, sedges, and ferns. A rhizome may produce leaves directly, as in the water lilies and the ferns, or it may produce an aërial stem bearing leaves, as in Solomon's seal.

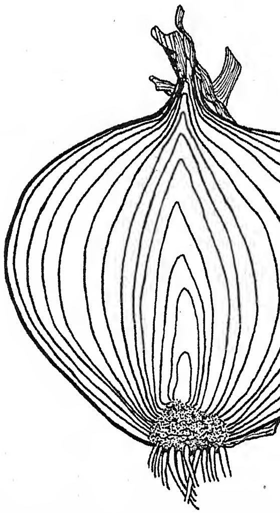

FIG. 39.—Longitudinal section of an onion bulb. The solid portion at the base is the stem. This bears fibrous roots below and thick leaves above. The leaves form the main portion of the bulb. The lines indicate the boundaries between the leaves. (Drawn by M. W. Phifer.)

A tuber is a short, relatively thick stem, and is illustrated by the potato (Fig. 40). The "eyes" of the potato are buds, from which new stems arise, and the plant is readily propagated by cutting the tuber into pieces, each one of which has a bud and enough of the adjoining tissues to supply food for the developing plant until it can establish itself. The potato is composed largely of storage parenchyma, and its cells contain numerous starch grains (Fig. 67). It has a thin layer of woody tissue which appears in the cross-section as a circle about $\frac{1}{4}$ inch from the outside (Fig. 40). The part outside of this is the cortex, composed of a thick layer of parenchyma with several layers of corky cells at the outside.

The part inside of the circle is the medulla, and is composed of an outer and an inner portion. The latter is somewhat more translucent that the former, as may be easily seen by cutting a thin slice from a potato and holding it toward a light. This greater translucence is probably due to the fact that cells contain less starch than those of the outer medulla.

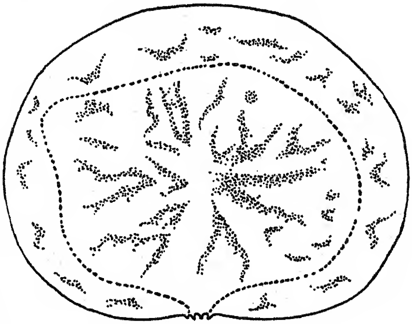

FIG. 40.—Diagrammatic cross-section of a potato tuber. A bud is indicated at the bottom of the figure, and the dotted line extending out to this indicates the circle of xylem. The other portions are mainly parenchyma in which starch (Fig. 67) is stored. (Drawn by E. C. Angst.)

A bulb is an underground structure or organ whose main bulk consists of thickened leaf bases, the stem being short and relatively small. It is illustrated by the onion, a vertical section of which is shown in Fig. 39. The food in common bulbs is stored largely in the thickened leaf bases, and in many bulbs, such as that of the onion, the outer leaf bases are thin and their function is largely protective.

BUDS.

Buds (Fig. 17) are the embryonic stage of branches and flowers. Some of them produce only the branch, some produce only flowers, and some produce both. Most of the buds of shrubs and trees are produced in summer, remain dormant during the winter, and resume growth in the spring. These are called winter buds, and are seen in willows, conifers (Fig. 126), lilacs, and many other common woody perennials. Such buds are usually protected by scales, and many of them

also have a covering of woolly hairs within the scaly covering. Willow buds have only one scale, but those of cottonwood, horse chestnut, pines, firs, lilacs, and many other trees and shrubs have several. These scales overlap, and in many species the joints are made water-tight by the presence of resinous or mucilaginous material. Resinous material is present in Douglas fir buds and mucilaginous material in cottonwood buds. Some woody perennials (*e. g.*, the cascara tree) have naked buds. In these there is no scaly covering of the bud as a whole, but each embryonic leaf is folded on its mid-rib and coated with resinous material. The embryonic flowers are coated with similar material.

Among the dangers from which buds are protected are: (1) the excessive loss of water by evaporation; (2) sudden changes of temperature; (3) mechanical injury; and (4) the entrance of organisms that might cause decay. Plants take in very little water from the soil during the winter when the soil temperature is low, and the cells of the embryonic organs of buds would be in danger of death if they should lose much water. Buds can endure low temperatures if the change from high to low or the reverse is gradual, and the protective coverings of winter buds are such as to insure this as long as they remain dormant. They are easily killed by low temperatures, however, if they have begun development and have ruptured their protective covering. The soft tissues which make up the embryonic leaves and flowers in buds might be injured by mechanical contacts if they were not protected by a hard covering, though, of course, many buds might escape such contacts. Organisms that cause decay (see p. 212) are present almost everywhere, and the entrance of these is prevented by the coverings present on winter buds.

Many herbs and some shrubs produce buds in spring and summer which develop without a dormant stage, and protective coverings are either absent or less complete than in winter buds. Illustrations are seen in such herbs as trilliums and buttercups and such shrubs as roses.

Suggestions for Further Reading.

The books listed under Chapter I.

CHAPTER IV.

ROOTS.

THE root (Figs. 2 and 41) is the portion of the plant axis that grows underground and does not bear leaves, and is thus contrasted with the stem which grows in the air and does bear leaves. The distinction between stems and roots, based on the presence of leaves in the former and their absence in the latter can generally be relied upon. The leaves of a stem may be rudimentary and inconspicuous, but they are always present in some form, while roots do not have even rudimentary leaves. Though there are important exceptions to the statement that roots grow in soil and stems grow in air, the statement holds quite generally for land plants. Examples of plants whose roots grow in some other medium than soil are orchids, whose roots will flourish in moist air; some ivies whose roots grow in air and assist the plant in climbing; and the duckweed whose roots grow in water. Some stems grow in soil and some in water. In the common ferns the entire stem is underground, and in the Solomon's seal the perennial portion of the stem is underground, while the annual portion is in the air. In many aquatic plants all or a large portion of the stem grows in water. From the functional standpoint the root may be defined as the portion of the plant axis that anchors the plant in the soil and enables it to absorb water. This statement holds generally for land plants.

COMPARISON OF ROOTS AND STEMS.

A more definite notion of the characters of roots may be had by following out the differences between roots and stems. The roots of vascular plants are relatively more uniform in structure than the stems of this group.

Roots usually have no definite system in the arrangement of their branches, while stems do. This may be illustrated by the roots of maples and willows. Maple stems have

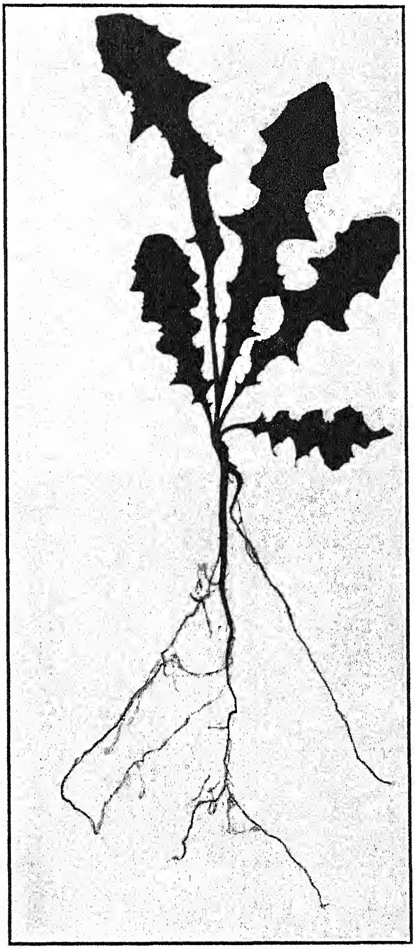

FIG. 41.—A young dandelion plant, showing leaves, and tap root with branches.

opposite branches, and willow stems have a definite system of spiral branching, but the root branches of these plants are not arranged on a definite system. Where roots do show a system of branching it is not commonly the same as that of the stems of the same species.

The origin of branches in roots (Fig. 43) is also different from the origin of branches in stems, being internal in roots and external in stems. The branches of a root originate from the cells of a relatively permanent tissue (the pericycle),

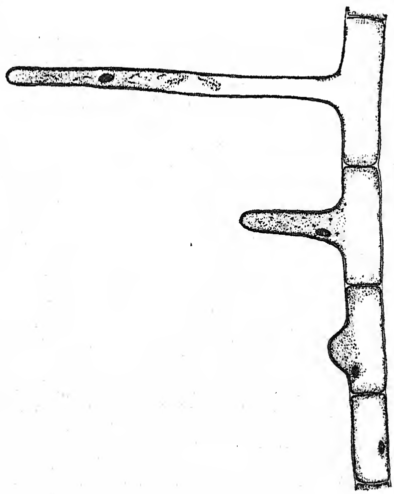

Fig. 42.—Root hairs, showing three stages in their development from the surface cells of the root. (Drawn by M. W. Phifer.)

which forms the outer layer of the vascular cylinder (stele), and push through the cortex either mechanically or partially by the absorption of the cortical cells, while the branches of stems originate from the meristematic tissue in growing points. This mode of origin is evident in young roots and in fleshy roots even when they are old, but is not evident in older woody roots, such as those of trees and shrubs, because the origin has been obscured by changes due to secondary growth. This origin is best seen in young roots by viewing

longitudinal sections through the microscope, but in fleshy roots, such as those of the parsnip (Fig. 43), it is readily seen by merely splitting the root in two with a knife, and may be further demonstrated by carefully peeling off the thick cortex and leaving the root branches still attached to the pericycle, which lies adjacent to the woody tissues. The pericycle of a root is not generally characterized as a growing tissue, but its cells have the power of passing, in local regions, into a meristematic condition, and thus producing new growths, while the tissue from which stem branches originate is characteristically meristematic.

The primary vascular tissues of roots show a radial arrangement in which the bands of phloem alternate with the bands of xylem (Fig. 44), while stems have collateral, bicollateral, or concentric bundles. Many roots have four bands of xylem but the number may be more or less, and no definite number can be stated as characteristic. The number of bands of phloem is normally the same as of xylem. Secondary growth obscures the radial structure of roots so that old woody roots, such as those of willows or pines, show much the same structure as the stems, except for the absence of pith.

The absence of pith (Fig. 44) is characteristic of roots, while its presence is characteristic of stems (Fig. 31). The distinction is readily seen by cutting across the stems and roots of such trees as willows and pines with a saw or a pocket knife. This character of roots is due to the manner in which the xylem develops. The later primary xylem (metaxylem) develops toward the center of the root from the first primary xylem (protoxylem), and thus commonly extends to the center of the root, while in stems the metaxylem develops outwardly from the protoxylem and the parenchyma cells within the xylem form the pith. There are, however, some roots that have pith. Large, fleshy roots, such as those of carrots and parsnips, have a large amount of pith-like parenchyma, though some vascular tissues may be found in it, and pith is also found in monocot roots, such as those of smilax and sweet flag, and in the roots of some dicot herbs. The primary xylem of roots always develops toward the center, and the presence or absence of pith depends on

whether the xylem stops before it reaches the center or develops all of the way to the center.

The root cap is a characteristic structure that has nothing corresponding to it in stems. This cap protects the root tip,

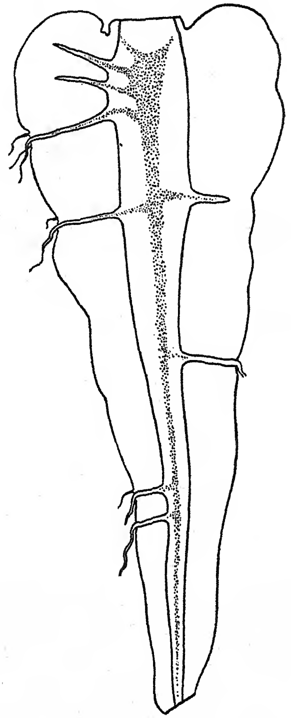

FIG. 43.—Diagrammatic longitudinal section of a parsnip root. The outer portion is the thick cortex, and the inner portion is the stele. The central portion of the stele is stippled to show a slight difference in appearance. The origin of the branches from the surface (pericycle) of the stele is shown. The cortex is composed of parenchyma, and much of the interior of the stele is composed of the same tissue. (Drawn by E. C. Angst.)

and its presence correlates with the fact that the growing root tip pushes forward through the soil against mechanical resistance, while the growing stem tip is usually in the air, and meets with no mechanical resistance.

The root cap is absent in parasitic roots and in most aquatic roots. One of the plants, however, in which root caps are readily seen is the water hyacinth (*Eichhornia crassipes*), whose roots commonly grow in water, but often penetrate into the mud under shallow water. The root cap in this plant is often ½ inch in length, and may be readily pulled off with the thumb and finger.

ORIGIN AND GROWTH OF ROOTS.

The first root of a seedling originates from the meristematic tissue in the seed, and in some seeds several roots originate from this tissue. The radish and the dandelion (Fig. 41) are examples of the first and rye (Fig. 135) and corn of the second. The first root of the radish develops into a tap root, and is a part of the permanent root system of the plant, while the first roots of wheat form a temporary system which soon dies, and is replaced by other roots formed a little farther up the stem, just beneath the surface of the soil.

All roots, of course, grow in length and some in thickness. The elongation of roots differs from that of stems in two particulars. The first is that the elongating region of a root is much shorter than that of the stem of the same species. The second is that the cell or tissue from which the root grows in length is inside of the root tip, while the corresponding cell or tissue is at the surface in the stem, and the growth resulting in elongation is thus sub-apical in roots, while it is apical in stems. In some ferns the elongation takes place from a single apical cell, but in seed plants it is usually from a group of meristematic cells. In either case cells formed toward the tip contribute to the growth of the root cap, and serve to renew it, as its outer cells are worn off by contact with the soil as the root pushes forward. There are some differences of detail in the origin of the root cap, but in most cases it originates from the meristematic region.

Other cells produced by division of the apical cell or the meristematic cells gradually differentiate into the various tissues of the root. Three regions are early distinguished. The outer one develops the epidermis, while the central one

marks the region in which the vascular cylinder (stele) will develop, and the one between these two marks the region in which the cortex will develop. The inner boundary of the cortex is usually marked by a definite layer of cells called the endodermis, and next to this, at the surface of the stele, is a relatively permanent region called the pericycle, from which root branches originate.

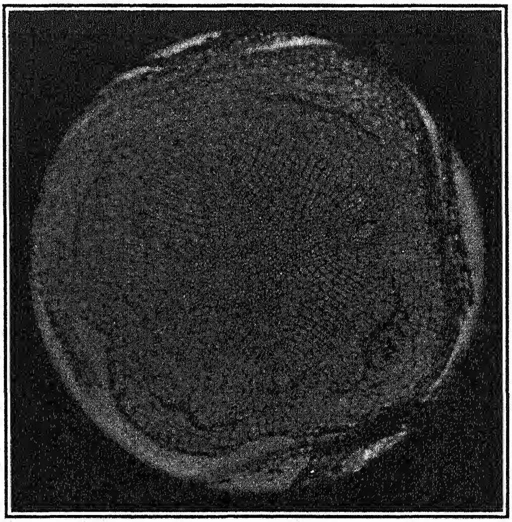

FIG. 44.—Cross-section of young root of pine. The xylem forms the center and has four radiating arms with a resin canal at the tip of each. The phloem occupies the spaces between the arms of xylem. The xylem and phloem make up the stele and outside this is the cortex. (Photomicrograph by H. P. Brown.)

In roots which have secondary thickening the cambium originates as separate strands, one adjacent to each band of phloem on the side toward the center. By division of these cambium cells the secondary xylem and phloem are produced and gradually the bands of cambium are extended laterally, so that they soon form a cylinder. After this stage the structure of a root having secondary growth approaches that of the stem, and in old woody roots the

two members are strikingly alike, except that the root shows no pith and its bark is thinner, due to decay of its older portions in the moist soil. The wood of such a root will show annual rings and wood rays, and cork will be formed from cork cambium.

Since the structure of a root is different from that of a stem, there will, of course, be a transition region between the two, but this region is usually short. It is usually more evident in young plants than in older ones, and in perennial plants a few years old it is not conspicuous by either external appearance or internal structure.

FUNCTIONS, FORM, AND STRUCTURE OF ROOTS.

The principal functions of roots are anchorage, absorption, conduction, and storage, and these functions are readily correlated with form and structure. Practically all roots perform the first three, while the last is emphasized in only certain kinds of roots. The form and structure of a root system is not, of course, correlated with any one function alone, but rather with the work of the root system as a whole.

The anchorage of a large tree, such as an oak or a pine, presents very different problems from the anchorage of a small plant, such as a buttercup or a wheat plant. In trees the roots are large and woody, and the portion of the root system close to the stem bears much of the weight of the trunk and other aërial parts, while these and the smaller root branches extending widely through the soil function in anchoring the plant in the soil and preventing it from being overturned by winds. Some trees, such as the oaks, develop a rather large tap root extending directly down, while others, such as the Douglas fir, develop large lateral roots, extending widely and occupying only the region near the surface of the soil. The general character of the root system of trees as well as of other plants is much influenced by the physical properties of the soil, the amount of water in the soil, and the amount of air in it. In general a rather hard soil with abundant water tends to cause a widely extending root system close to the surface, while a porous soil with a smaller

water supply and the consequently greater abundance of air in the soil tends toward a deeper root system. Cypress trees grow in soil that is often covered with water, and they develop special root branches called knees which extend upward into the air, and enable the gases of the air to diffuse into the roots.

The root system of a small herbaceous plant, on the other hand, does not support a heavy weight, and is likely to consist of more slender, flexible roots with a small, tough vascular cylinder in the center and a larger, soft cortex surrounding it. Such a root structure when accompanied by extensive branching makes for firm anchorage of small plants. There may be a large tap root with numerous branches, as in the common pig weed (*Amaranthus retroflexus*), or numerous slender roots originating directly from the stem, as in wheat and other plants of the grass family. The root system of wheat branches freely, and forms a fine network in the upper 2 or 3 feet of the soil, and sometimes extends to as great a depth as 5 feet.

The anchorage of a corn stem presents some unusual features. Though it has an extensive system of roots originating underground, additional anchorage is provided by the development of one or more whorls of "prop" roots above the surface of the soil. These grow as stout, unbranched structures diagonally downward into the soil, where they branch freely. The stalks of some varieties of corn reach a height of 8 feet or more, and the weight of the stalk, leaves, and ear, together with the large exposure of surface to winds, would result in considerable danger of tipping over if firm anchorage were not provided.

The absorption of water by roots takes place largely through root hairs (Fig. 135). These are commonly located in a limited region, just back of the root cap, and as the older ones die new ones are formed on the growing region, close to the root cap. The total number of root hairs thus remains somewhat constant, though the life of any one hair is short. In some roots, however, the region of hair production is much more extensive, as may be seen on the roots of the wandering Jew (*Tradescantia*), grown in water. Some roots

do not have hairs, and in such cases water is taken in through the surface cells.

Root hairs are delicate structures (Fig. 42); each formed by the outgrowth of a surface cell of the root. In this way the absorbing surface of the root is greatly increased and is often ten times as great as it would be without hairs. The wall is thin, and water readily penetrates it. Root hairs when grown in water or moist air are regular in form, but when grown in soil they apply themselves closely to the soil particles and are thus much distorted. Substances in solution in the soil water may enter the root with the water if the plasma membrane of the root cells is permeable to them.

From the surface cells, of which the root hairs are prolongations, the water moves through the cortical cells and any other intervening cells to the vascular tissues in the stele. From here the conduction is much the same as conduction in the vascular tissues of the stem.

Storage in roots is mainly in parenchyma tissues. Fleshy roots, such as those of the carrot and the parsnip, have a large cortex and a considerable amount of central parenchyma with a relatively small amount of vascular tissue between the two. Carrots contain sugars and proteins, and parsnips contain sugars, fats, and some starch.

The development of storage tissue in the beet root is quite different from that in the carrot and the parsnip. Rings of growth are plainly seen by cutting across a beet, and these are formed by the activity of successively formed layers of cambium. The original cortex is broken by the growth of a new cortex from the pericycle and soon disappears. A new cambium is formed in this new cortex, and it produces a new growth ring consisting of some xylem and some phloem, mainly parenchyma. When this cambium dies a new one is formed in the outer portion of the parenchyma and a new growth ring is produced. In this way eight or ten growth rings may be produced, in the parenchyma of which sugars and proteins are stored.

The development of fleshy storage roots, such as those of the carrot, parsnip, and beet, is common in biennial plants. Food is stored during the first year of the plant's life, and

this is utilized in the production of an aërial leafy stem during the second year. This stem produces flowers, fruits, and seeds, thus completing the life cycle. These plants are, however, not always biennial. In some cases the whole life cycle occurs in a single season, and in others the plants tend to become perennial.

Some plants, such as the dahlia and the sweet potato, produce numerous fleshy storage roots instead of a single fleshy tap root, and the root system thus has a different form. A cluster of fleshy roots, such as those of the dahlia, is called a fascicled system. The sweet potato contains sugar, starch, fat, and protein. A carbohydrate (inulin) resembling starch in composition, but differing from it in being in solution instead of in the form of grains, is stored in the roots of the dahlia and the Jerusalem artichoke.

Suggestions for Further Reading.

1. Weaver, J. E.: Root Development of Field Crops, New York, 1926.
2. The books listed under Chapter I.

CHAPTER V.

FLOWERS.

THE flower is a reproductive organ. It produces seeds, and these grow into new plants, and the parts of the flower are suited by form, structure, color, and odor to this function of seed production. Incidentally the forms, colors, and odors of many flowers are pleasing to human senses, and flowers are among the most attractive objects in Nature.

THE PARTS OF THE FLOWER.

The parts of the flower are modified leaves, and the flower is a modified branch which has no buds in the axils of its leaves. A complete flower (Fig. 47) is composed of four circles, or whorls, of parts—sepals, petals, stamens, and one or more pistils. The leaf-like character is apparent in the sepals, and is often recognizable in the petals, but is not so evident in the stamens and pistils. A transition from sepals to petals and stamens is seen in the white water lily, but not usually in other flowers. The flower is borne on a receptacle (Fig. 47), which is a portion of the stem or of a branch, and vascular bundles extend from the stem or branch into the sepals, petals, stamens, and pistils.

The sepals are the outer whorl, and constitute the calyx. Their leaf-like nature is indicated by their green color and the presence of veins and other tissues similar to those found in leaves. The petals are next in order and, taken collectively, constitute the corolla. Although they are somewhat leaf-like in form and structure, they are usually of some other color than green, such as white in the Easter lily (Fig. 45) and yellow in the buttercups.

The stamens (Fig. 47) constitute the third whorl. Each stamen is composed of a stalk-like portion called the filament

FIG. 45.—Easter lily flowers and buds.

and an enlarged portion at the top called the anther, which produces the pollen. An anther is made up essentially of pollen sacs (usually two), which open at maturity and discharge the pollen. The act of opening is called dehiscence and the most common method is by longitudinal splitting, though some (*e. g.*, *Rhododendron*) open by a small pore at the top.

FIG. 46.—Flowering branches of pale laurel (*Kalmia polifolia*). The leaves are evergreen.

The pistil (Fig. 53) is composed of three parts—ovary, style, and stigma. The ovary is the swollen portion at the base containing the ovules, which are usually borne in definite positions on the ovary wall, called placentas (Fig. 51).

In some flowers, however, the ovules are borne in the center of the ovary, and these may be on an outgrowth from the base of the ovary which originates from stem tissues.

The ovule (Fig. 53) is a rounded structure borne on a short stalk (funiculus). The basal portion of the ovule is the chalaza, and above it is the main body of the ovule (nucellus), surrounded by either one or two integuments. The chalaza is the meristematic tissue from which the other parts grow. There is an opening (micropyle) in the integuments, and in an erect ovule this is situated at the top, though many ovules are wholly or partially inverted so that the micropyle is situated near the base of the ovule, close to the funiculus.

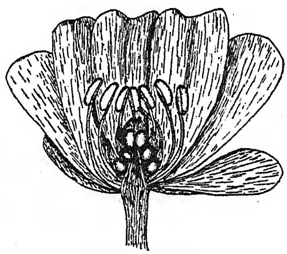

FIG. 47.—Longitudinal section of buttercup flower, showing sepals, petals, stamens, and pistils. All borne on the receptacle. (Drawn by E. T. Bodenberg.)

The embryo sac (see p. 293) is contained within the nucellus. The function of the ovule is the production of a seed, and the relation between these two structures is discussed in the Chapter VI.

The stigma is the portion of the pistil that receives the pollen, and its character is such as to suit it to this function. Many stigmas are sticky, so that the pollen adheres to them, and others are covered with short hair-like outgrowths, among which the pollen lodges. The style is the portion of the pistil between the ovary and the stigma. It may be long or short, or may be entirely absent, and in the latter case the stigma is borne directly on the ovary.

In the evolution of a flower from a branch the pistil has

developed from one or more modified leaves. A leaf modified so that it produces one or more ovules is called a carpel, and every pistil is structurally made up of 1 or more carpels. The pistil is made up of 1 carpel in the buttercups, 3 in the trilliums, and 5 in the rhododendrons. The number of carpels may be indicated by the number of stigmas or even of styles, or by the number of lobes in the ovary, but is usually most evident in a cross-section of the ovary (Fig. 51), where it is indicated by the number of placentas. The monocarpellate character of the buttercup pistil is evident from the single style and stigma, the ovary without lobes, and the single placenta; the tricarpellate character of the trillium pistil is evident from the 3 stigmas, three-lobed

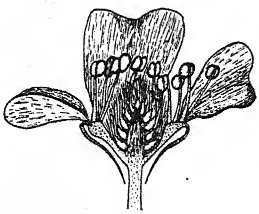

FIG. 48.—Longitudinal section of flower of giant avens (*Geum macrophyllum*). (Drawn by E. T. Bodenberg.)

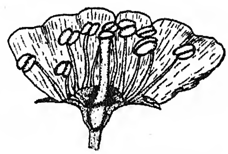

FIG. 49.—Longitudinal section of hawthorn (*Cratægus*) flower. Inferior ovary; petals and stamens on calyx. (Drawn by E. T. Bodenberg.)

ovary, and 3 placentas; and the fact that the pistil of the rhododendron flower is composed of 5 carpels is evident from the 5 cells (divisions) and 5 placentas seen in the cross-section of the ovary.

TWO FLOWERS DESCRIBED.

Descriptions of two representative flowers will help in giving definite ideas of the flower parts. The buttercup flower (Fig. 47) has 5 or more green sepals, all separate from one another, and 5 or more yellow petals, also separate. Its stamens are numerous and yellow, and each filament bears an anther composed at maturity of 2 pollen sacs which set

their pollen free by splitting longitudinally. The pistils are numerous and separate, each composed of a single carpel and having only 1 ovule. All of the parts of the flower are borne on the receptacle, none of the circles are united, and there is no union of any of the parts within any circle.

The flower of the Easter lily (Fig. 45) has a perianth composed of 6 white parts slightly united at the base, which are all alike and, therefore, not readily distinguished as calyx and corolla. The term perianth may be used to include the calyx and the corolla in any case, but is especially advantageous in such flowers as this, where these two circles are similar in form and color. This flower has 6 yellow stamens and 1 pistil. Each stamen has a long filament and an anther, composed of 2 pollen sacs which split longitudinally in the discharge of their pollen. The anther is attached to the end of the filament by its middle, and thus swings freely. Anthers so attached are called versatile. The ovary has 3 cells and 3 placentas, and is thus seen to be composed of 3 carpels. The style is long, and the stigma is three-lobed and sticky. All of the parts of this flower are borne on the receptacle, but there is some union of parts, the 6 parts of the perianth being slightly united at the base and the 3 carpels completely united into 1 pistil.

KINDS OF FLOWERS.

The organs necessary for the production of seeds in the angiosperms are stamens and pistils, and these are known as the essential organs of the flower. If both are present in the same flower the flower is perfect, while if either is lacking it is imperfect, those with stamens being staminate and those with pistils being pistillate. Castor-bean plants, alder trees, and some other plants have the staminate and pistillate flowers on the same individual plant, and are termed monoecious, while willows, poplars, hemp, and some others have the two kinds of flowers on different individuals, and are termed dioecious.

The parts composing any one of the circles of a flower are more or less united in many species. The petals may be

separate, as in the buttercup, slightly united at the base, as in the Easter lily, or more completely united so that their number is indicated only by the lobes of the corolla, as in the foxglove. Similarly sepals may be either united or separate. Stamens may be separate (Easter lily), united by their anthers (dandelion), or united by their filaments so that they form a tube (sweet pea) or column (mallow). The union in the dandelion is shown in Fig. 56.

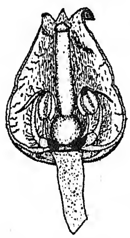

FIG. 50.—Longitudinal section of flower of madrona (*Arbutus Menziesii*). Corolla of united petals; anthers bearing appendages and opening by a terminal pore. (Drawn by E. T. Bodenberg.)

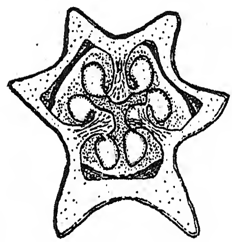

FIG. 51.—Cross-section of trillium ovary (*T. ovatum*), showing the three placentas and two of the ovules borne on each. (Drawn by E. T. Bodenberg.)

The four circles of parts in the flower may all be separate on the receptacle, or two or more of them may be united, or the parts of one circle may be apparently borne on another circle (Fig. 49). If they are all borne on the receptacle, and none of them united with the ovary, the flower is hypogynous and the ovary is superior, as in the Easter lily and the buttercup. If other parts are borne on the ovary they are epigynous and the ovary is inferior, as in the flowers of huckleberries and apples. Petals may be borne on the calyx, as in carrot flowers, and stamens may adhere to the corolla, as in the morning glory, or may be borne on the calyx, as in apple blossoms. A flower with the circles separate is shown in Fig. 47, and one with some union of parts in Fig. 48.

The perianth may be conspicuous, as in the violets and the Easter lily; consist of mere scales, as in the grasses (Fig. 135);

or entirely absent, as in the cat-tail. Flowers which have an abnormal number of petals are called double flowers. In some flowers this is due to the presence of adventitious petals, and in others to the transformation of stamens or pistils into petals. Still another method of doubling is seen in some flowers of the composite family (*e. g.*, sunflower), in which some of the disk flowers have become similar to the ray flowers. Many double flowers have been developed in cultivation by selection and vegetative propagation. One variety may have double flowers, while another variety of the same species may have single ones. Among the attractive double flowers common in cultivation are roses, carnations, chrysanthemums, dahlias, and the snowball.

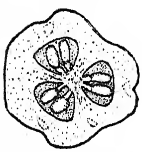

FIG. 52. — Cross-section of ovary of *Iris*. A three-celled ovary. (Drawn by E. T. Bodenberg.)

Flowers may be regular (*e. g.*, buttercups) or irregular (*e. g.*, sweet peas). A regular flower is one that has all of the parts of any one circle alike, and an irregular flower is one in which some of the parts differ from other parts of the same circle. In the sweet pea the petals are not all alike, 1 being the standard, 2 others united forming the keel, and the remaining 2 at the sides being the wings. Irregularities are also seen in other parts of the flower. A regular flower, such as that of the buttercup, can be divided into two similar halves by more than one longitudinal plane, and is called actinomorphic, while an irregular one, such as the sweet pea, can be divided into similar halves by only one longitudinal plane, and is called zygomorphic.

POLLINATION AND FERTILIZATION.

The transfer of pollen from the anther to the stigma is called pollination. If pollen reaches the stigma of the same flower the process is self-pollination, and if it reaches the stigma of another flower it is cross-pollination. While self-pollination occurs in some flowers, it is rendered impossible in others by the fact that the stamens and pistils do not

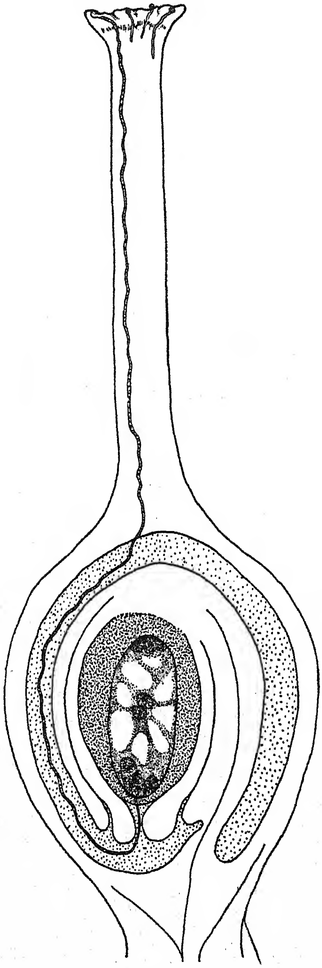

FIG. 53.—Diagrammatic longitudinal section of a pistil, showing ovary, style, and stigma. The ovary contains one ovule and it shows the nucellus, the two integuments, and the micropyle. The space between the ovary wall and the ovule is lightly stippled; the nucellus is more heavily stippled. The eight nuclei (see text) are shown in the embryo sac. Several pollen grains have germinated on the stigma, and a pollen tube from one of these (see text) has reached the embryo sac. (Drawn by M. W. Phifer.)

occur in the same flower or by the fact that the pollen in any one flower is not shed at the time that the stigma is in the proper stage to receive it. The pollen may be shed before the stigma of the flower is mature or not until after it has withered. The former is the more common case, and is illustrated by the dandelion. The flowers are in heads, the outer ones maturing first so that the stigmas of the flowers farther in are in the stage to receive the pollen when the outer flowers are shedding it, and cross-pollination is effected by insects. Self-pollination is also possible in dandelion flowers by the recurving of the stigmas so that they touch the anthers. In the figwort (*Scrophularia*) the stigma of any one flower matures before the anthers of that flower split open, and withers before the pollen is shed, but the stigma of some other flower is then ready to receive the pollen, which is transferred to it by insects. In willows the staminate and pistillate flowers are on separate trees, and the pollen is transferred mostly by insects.

The principal agents of the transfer of pollen in cross-pollination are wind and insects. Among the plants that are wind-pollinated are oaks, birches, ragweeds, sedges, and many grasses. In such plants the pollen is usually dry, light, and abundant, and the stigmas are usually feathery. Flexibility of the stem or of the inflorescence axis or the possession of versatile anthers facilitates the shaking out of the pollen by wind. Sedges, grasses, and ragweed have flexible stems and the anthers of grasses are versatile. The staminate catkins of oaks and birches are flexible and pendulous at the time that their pollen is shed.

Among the many plants that are insect-pollinated are buttercups, trilliums, orchids, and sage. In such plants the pollen and the stigma are usually both sticky, and the visits of insects are assured by the color or odor of the flower. Many insect-pollinated flowers are irregular, and their form is such as to make the transfer of pollen certain. In orchids the pollen is in sticky masses, and the form of the flower is such that these masses adhere to the proboscis of the visiting insect, and are thus transferred to the stigma of the next flower visited.

Fertilization in angiosperm flowers is the union of nuclei from the pollen tube with nuclei in the embryo sac. Pollination precedes fertilization, and is the means to that end. When the pollen grain germinates on the stigma it sends its tube through the tissues of the style into the cavity of the ovary, where its tip comes into contact with the ovule, and thus conveys the pollen nuclei to the nuclei of the embryo sac. When fertilization has taken place the ovule develops into a seed.

FIG. 54.—Flowers and fruits of dandelion. At the left, top view of two heads. Next, a flower stalk (scape) and head of flowers with involucre. Next, a flower head with the front half cut away to show the receptacle. Next, a head with ripe fruits, showing parachute of hairs. A portion of the receptacle is seen where some of these have fallen away. At right, another head, showing more of the seed-like fruits.

INFLORESCENCE.

The arrangement of flowers on the plant is called the inflorescence. The flowers may be solitary, as in the violets and the trilliums, or they may be in groups, as in the cherries and the garden pea. If there is a central axis along which the flowers are borne, and each flower is borne on a stalk (pedicel), as in the shepherd's purse (Fig. 2), and the *Laburnum* tree (Fig. 57) the inflorescence is a raceme. If the

flowers are sessile along an axis, as in the common roadside plantain, the inflorescence is a spike. If the spike is short and scaly, as in the willow (Fig. 136) and the hazel, it is called a catkin, or ament. If the pedicels of the lower flowers of a raceme become very long so that the inflorescence is flat-topped we have a corymb, such as is seen in some species of cherry. If all of the pedicels originate from the end of the stem or branch, as in sweet cicely (Fig. 139) and the onion, the inflorescence is an umbel. If all of the flowers are crowded together at the end of the stem or branch, as in the clover (Fig. 138) and the dandelion (Fig. 55), and the flowers

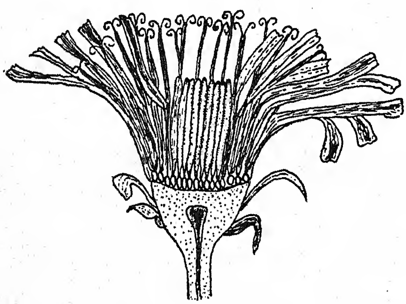

Fig. 55.—Longitudinal section of head of dandelion flowers, showing receptacle and involucre. The flowers of the dandelion are all alike when mature, but the ones at the center here look different because they show a younger stage than those of the outer portion of the head. (Drawn by E. T. Bodenberg.)

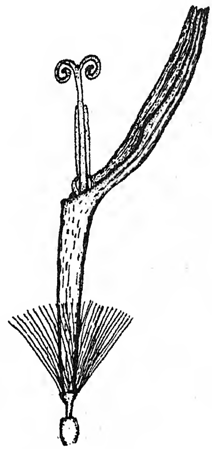

Fig. 56.—A dandelion flower. Ovary at base. Pappus, consisting of hairs, and representing the modified calyx. Corolla consisting of five united petals, with its strap-shaped (ligulate) portion extending to the right. Two recurving stigmas. Anthers united around the style. (Drawn by E. T. Bodenberg.)

are sessile or have very short pedicels, the inflorescence is a head.

The dandelion head is an example of the type of inflorescence that is characteristic of the composite family. It con-

sists of numerous flowers crowded together on a common receptacle, and surrounded by one or more rows of bracts constituting the involucre. The whole structure bears a striking resemblance to a single flower, but on examination is readily seen to be composed of many flowers.

In the grasses (Fig. 58) the spikelet is taken as the unit of inflorescence instead of the flower. The spikelet consists of one or more florets, and each floret consists of the pistil and stamens enveloped by two bracts, the lemma and the

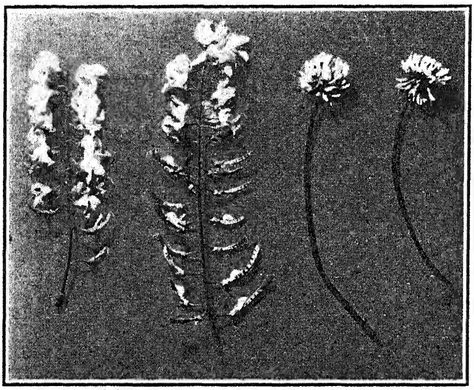

Fig. 57.—Inflorescence. The two at the left are racemes of *Laburnum*, showing flowers at top and fruits (legumes) at bottom. The two at the right are heads of white clover.

palet. The lemma and the palet are readily seen in unhulled oats. The inflorescence in common grasses is usually either a spike, as in wheat and the common rye grass (*Lolium*) (Fig. 58), or an irregularly branched inflorescence called a panicle, such as is seen in blue grass, brome grass (Fig. 58), and oats.

There are a number of other forms of inflorescence, and the inflorescence is frequently used as an aid in the classification of seed plants. The terms met with in keys and floras are usually defined in glossaries in these works.

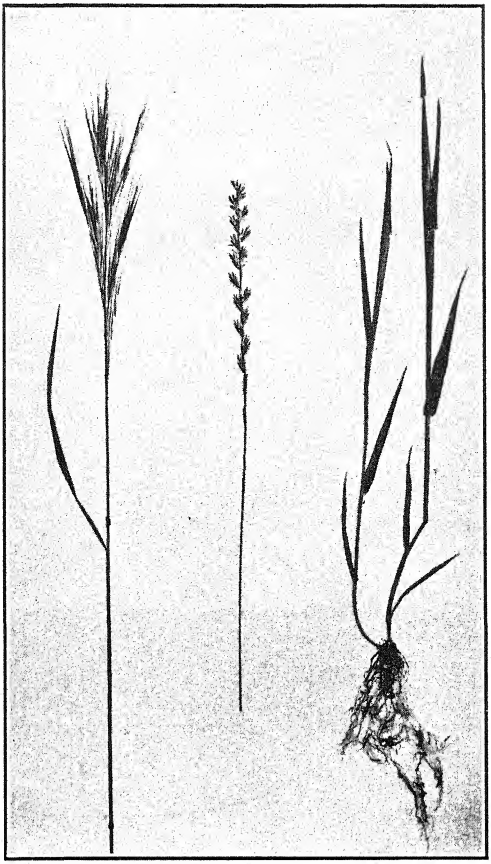

Fig. 58.—Grasses. Left, a brome grass (*Bromus*), showing stem, a leaf, and inflorescence (panicle). Center, perennial rye grass (*Lolium perenne*) with terminal spike, showing separate spikelets, each with several florets. Right, roots and leafy stems of velvet grass (*Holcus lanatus*).

Suggestions for Further Reading.

1. Clements, F. E., and Clements, E. S.: Flower Families and Ancestors, New York, 1928.

2. Pool, R. J.: Flowers and Flowering Plants: An Introduction to the Nature and Work of Flowers and the Classification of Flowering Plants, New York, 1929. (This book contains a good list of books about flowers.)

3. The books listed under Chapter I.

CHAPTER VI.

SEEDS.

A SEED is a young plant in a dormant condition, covered with a protective coat and provided with a supply of nourishment. It originates from the fertilized ovule, and its parts are traceable to the parts of the ovule and the nuclear fusions which occur there.

THE PARTS OF A SEED.

The young plant is the embryo, and shows some differentiation into the parts that are to produce the vegetative organs of the seedling. Usually one or more leaves, a stem, and a growing point can be seen, all in embryonic form. The seed leaves are the cotyledons, and there are usually 1 or 2, though in the pines and other conifers there may be several (3 to 18). The cotyledons may be very thin structures, distinctly leaf-like in form, as in the castor bean (Fig. 60), thick structures containing much stored food, as in the common beans (Fig. 59) or somewhat intermediate between these, as in the pumpkin and squash.

The embryonic stem in the seed commonly consists of two portions—that below the attachment of the cotyledons constituting the hypocotyl, and that above constituting the epicotyl. Both can be seen in the common beans (Fig. 59). The growing point is the plumule, and may be very inconspicuous, as in the pumpkin, or may be larger and even show embryonic leaves, as in the common beans (Fig. 59). The radicle is the portion that will produce the root, and is at the free end of the hypocotyl, but is not usually readily distinguished from it.

Food-containing tissue in the seed not forming a part of the embryo is endosperm, and the food stored there is com-

monly starch, oil, or protein. The protein is usually in the form of grains, and is called aleurone. In corn, wheat, and other grains a layer of aleurone cells covers the single mass

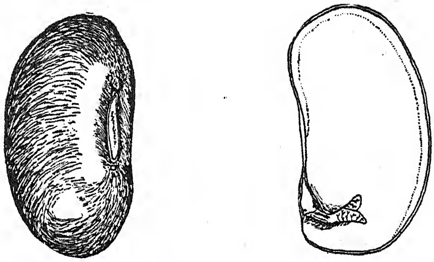

FIG. 59.—A bean seed. Left, whole seed, showing the large hilum and the small micropyle just above it. Right, the inner surface of one cotyledon with the hypocotyl (pointing upward) and the plumule (consisting of two young leaves) pointing toward the right. (Drawn by M. W. Phifer.)

of endosperm, while the cells of the interior contain numerous starch grains. The castor-bean seed has two large masses of endosperm forming the main bulk of the seed, and they are rich in oil and also contain some protein. Where endo-

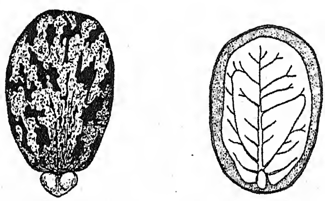

FIG. 60.—Castor-bean seed. Left, the whole seed, showing the caruncle at the bottom. Right, inner view of one-half of the seed, showing one cotyledon, the hypocotyl, and the endosperm. Venation is shown in the cotyledon. The hypocotyl is the short body at the base of the cotyledon. The stippled area indicates the portion of the endosperm not covered by the cotyledon. (Drawn by M. W. Phifer.)

sperm is present the cotyledons are likely to be thin and leaf-like, as in the castor bean, but some seeds, such as those of corn (Fig. 61), have abundant food stored in both cotyle-

don and endosperm. The seeds of pines and other conifers have a large mass of endosperm, with the embryo in the center.

The differentiation of parts in the embryo is largely in form, and the cells present are either parenchyma-like or meristematic. There is, however, some structural differentiation, and vascular bundles are often present, though poorly developed, and stomates and the beginning of veins are sometimes seen in embryonic leaves.

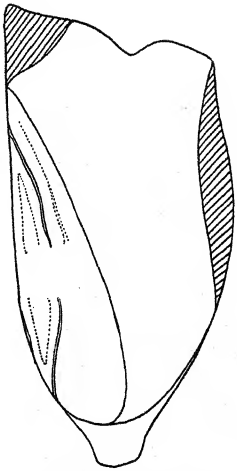

FIG. 61.—Longitudinal section through a kernel of corn. The cross-hatched areas indicate the hard yellow portions of the endosperm. The rest of the endosperm is left unshaded. The curved body at the left of the endosperm is the cotyledon. To the left of this the plumule points upward and the hypocotyl downward. (Drawn by E. C. Angst.)

The seed is enclosed in a seed coat called the testa, and there is usually an opening in this which is the micropyle (Fig. 59). This is easily seen in navy bean and pumpkin seeds. The fact that this is an opening through the testa is readily shown in the navy bean. If the seed is soaked in water, and its surface freed from excess water with a piece of filter paper, a drop of water comes out of the micropyle when the seed is pressed between the thumb and finger. A scar called the hilum is commonly seen on the outside of the seed, and this marks the point where the seed was attached to the fruit. In the common beans (Fig. 59) and pumpkin seeds the hilum and the micropyle are close together.

The testa protects the embryo from mechanical injury and from the attacks of microörganisms which would cause decay. In the navy bean the testa is hard and brittle when dry, but is soft and pliable after being soaked in water. The testa of the castor bean is also hard and brittle, but does not change much on soaking, since it is almost impervious to water. In this seed (Fig. 60) water is absorbed by a prominent

porous structure called the caruncle. The testa of the pumpkin seed is thick and tough and takes up water readily.

In addition to the parts already described, another structure, the arillus, is present in a few seeds. It grows from the meristematic tissue of the chalaza, and is outside of the testa, forming a more or less complete covering over the seed. The arillus of the nutmeg is a branched structure almost entirely enveloping the seed. This arillus is the mace of commerce and is used as a spice. An arillus is also present on the seeds of the white water lily and some other plants.

THE ORIGIN OF THE SEED FROM THE OVULE.

The study of the parts of the ovule and of the nuclear fusions which occur in its embryo sac (Fig. 53) during fertilization has made clear the origin of the various parts of the seed. The embryo and the endosperm of monocots and dicots arise from nuclear fusions within the embryo sac, and the testa develops from the integuments of the ovule. One male nucleus from the pollen tube fuses with the egg nucleus of the embryo sac, and thus forms the cell which grows into the embryo, while the other male nucleus from the pollen tube unites with a nucleus formed by the fusion of two embryo sac nuclei called the polar nuclei, and the cell which produces the endosperm is thus formed. The nucellus of the ovule is usually used up by the developing embryo before the seed is mature. The testa may be the product of one integument where there is only one on the ovule or it may come from only the outer one where there are two. The growth of the integuments into a testa follows as a secondary effect of the nuclear fusions that form the embryo and the endosperm. The origin of the parts of gymnosperm seeds, such as those of the pines and other conifers, is similar in a general way to that of monocots and dicots, except as to the origin of the endosperm (see p. 282).

SEEDS AND SPORES.

A seed differs from a spore in being a complex, many-celled structure with the beginnings of the vegetative organs

of the plant already formed, while a spore is usually a single cell capable of producing a young plant by division, which is followed by extensive differentiation in the more complex plants, such as the ferns. Some spores consist of more than 1 cell, often 2 or 4, but in that case the cells are all very similar in appearance.

GERMINATION.

Under suitable conditions of temperature and moisture the embryo of the seed resumes growth, and this resumption is called germination. Oxygen is necessary for germination, and this usually enters the seed in sufficient amount when the moist seed is in contact with the air. Light is not commonly a factor, and most of the common seeds will germinate either in light or darkness. Light is, however, favorable to germination in some species. The seeds of one species of tobacco remain dormant in the soil for several years, but germinate when exposed to light. Light is unfavorable to the germination of the seeds of a few plants.

Though the seeds of many plants will germinate as soon as they are ripe, delayed germination is rather common. The seeds of cultivated oats (*Avena sativa*) will germinate in the fall following the summer in which they are produced, while those of wild oats (*A. fatua*) will not germinate until the following spring. In some plants (*e. g.*, red clover) some of the seeds germinate promptly, while the germination of others of the same lot is delayed.

The causes of delayed germination may be grouped under five heads: (1) Seed coats impermeable to water. (2) Seed coats impermeable to oxygen. (3) Seed coats so stout that the embryo cannot break them. (4) Embryos immature. (5) After-ripening necessary.

Impermeability of seed coats to water is seen in some seeds of red clover and other plants of the legume family. In one legume the seeds were tested in October and none of them germinated when the seed coats were left intact, while all of them germinated when the seed coats were cut through with a file. All of the seeds of this species germinated readily

the following spring without treatment. Changes which allow the entrance of water into hard seeds occur under ordinary storage conditions, but take place more rapidly when the seeds lie on the soil out of doors, where moisture and other conditions vary and bacteria and fungi which may cause decay are present. The seeds of some plants of the mallow family also show delayed germination, due to hard coats which do not allow water to enter.

Delayed germination due to impermeability of the seed coats to oxygen is seen in the cocklebur (*Xanthium*) and some other plants of the composite family and also in several grasses. In these cases germination will occur in a very short time if the seed coats are removed or pierced with a pin. The same result follows if the seeds with coats intact are placed in pure oxygen so that the oxygen pressure on them is greater than it is in air.

The seeds of many water plants have coats that are so stout that the swelling embryo cannot break them, and further intake of water is thus prevented. Such seeds have been stored in water for as long as four years without germination. The water plantain (*Alisma*) illustrates this kind of delayed germination. If the seeds are placed in foul water, however, where bacteria and fungi are present, germination occurs in a short time.

Immature embryos are found in the seeds of some species of buttercups (*Ranunculus*) and also in some orchids and other plants. In some cases several weeks or even months are required for the development of the embryo to a stage where germination is possible. Placing the seeds on nutrient media and in certain conditions of acidity hastens the maturity of the embryos of orchid seeds.

A period of after-ripening is necessary before germination will take place in the seeds of one species of hawthorn (*Cratægus mollis*). Three or four months of after-ripening are necessary if the hard fruit coats are left on, but this period is much shortened if the fruit coats are removed, and is still further shortened if the seed coat is removed. After-ripening in this case seems to involve an increase in acidity, which causes changes favoring water absorption.

THE DEVELOPMENT OF SEEDLINGS.

As the young plant develops it escapes from the seed coats, breaks through the soil, produces roots and green leaves, and thus becomes established and capable of an independent existence (Fig. 62).

In the development of the young plant the endosperm, if present, remains under ground, and the foods stored in it are used up in growth. The cotyledons may remain underground, as in the garden pea and corn; come above ground as very temporary somewhat leaf-like structures, as in the navy bean; or they may form the first leaves, different in appearance from the later ones, as in the pumpkin and the castor bean. Two functions, food storage and foliage work, are thus performed to varying extents by the cotyledons of different seeds. In the first case just mentioned the function is wholly storage, and the starch, oil, protein, and other stored foods are used up in the development of other parts of the seedling. In the second case both functions are performed, since the cotyledons are abundantly stored with starch which is used up in the growth of the seedling, and they become green, though not very leaf-like in form; while in the third case the function seems to be wholly a foliage one, since the cotyledons are leaf-like in form even in the seed, and become distinctly so in structure and color as they develop.

The seed coats are commonly left underground in the development of the seedling, though they are sometimes pushed up through the soil on top of the developing cotyledons, a phenomenon characteristically identified with the pines. Where the seed coats are left underground the escape of the embryo is often accomplished by the irregular bursting of the seed coat by the increase in the size of the embryo, as in peas and beans. In pumpkins, squashes, and other seeds of their family the escape from the seed coats is accomplished by a special device. The seed coats are caught and held by a peg-like process developed on the side of the lower portion of the hypocotyl, and the cotyledons

are pulled out of them by the formation and elongation of an arch in the hypocotyl above this peg-like process.

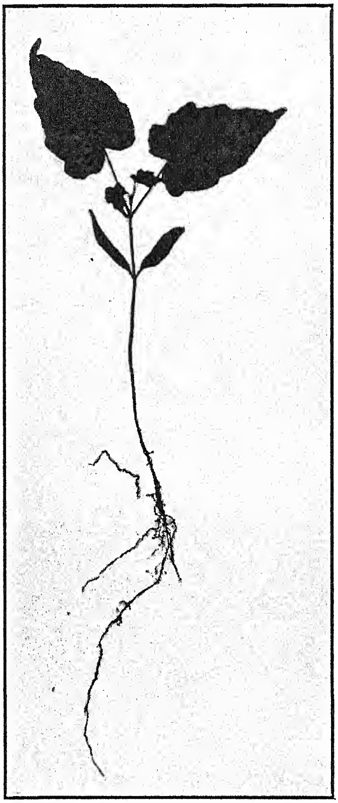

FIG. 62.—A maple seedling, showing leaves, stem, and roots. The first pair of leaves (formed by the cotyledons) differ in form from the two pairs above them.

Breaking through the soil above the seed requires considerable force, and the problem of accomplishing this without injury to the delicate parts of the developing embryo is solved in different ways by various seeds. In the bean,

castor bean, and pumpkin the arch of the hypocotyl breaks the soil, and the plumule and the cotyledons are thus pulled up without exposure to mechanical injury. When they are free from the soil the arch straightens and the seedling becomes erect. Corn pushes its first leaves directly through the soil and the plumule is protected by them. The pines do the same, but since the seed coat is commonly brought up on top of them the cotyledons are somewhat protected by it.

SEED DISPERSAL.

Many seeds are dispersed by various agencies which carry the fruits in which they are contained, but in some plants the seeds themselves are of such a character as to enable them to be carried by wind, water or other agents. The seeds of milkweeds and fireweeds have a tuft of hairs and those of the catalpa tree have a wing, and these seeds and many others are widely scattered by wind. The seeds of the white water lily have a thick arillus, and this enables them to float on water. Various devices of seeds and fruits resulting in the wide dispersal of the seeds are readily seen by any one interested in making the observations.

Suggestions for Further Reading.

The books listed under Chapter I.

CHAPTER VII.

FRUITS.

THE term fruit when used in botanical descriptions has a somewhat broader meaning than when used in the popular sense. As popularly used the term is not very exact, but we are likely to think of it as including plant parts that are fleshy, juicy, edible without cooking, and usually containing

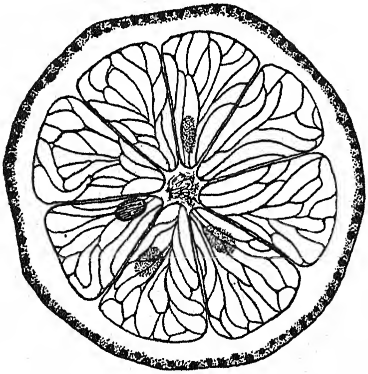

FIG. 63.—Cross-section of a lemon, showing "rind," pulp, and seeds. Oil glands are shown at the surface of the rind. (Drawn by M. W. Phifer.)

seeds. The botanical meaning is more definite and designates all plant parts that consist of matured and developed carpels together with any other parts that may be incorporated with them during this development. Most of the common fruits are developed from ovaries or intimately connected parts, but the word carpel is used in the definition to include such fruits as the berries of yews and junipers which are developed from carpels on which the ovules are borne naked,

and thus do not involve an ovary. In the general sense peaches and apples are fruits, while the grains of wheat and corn and the pods of locust and catalpa trees are not, but in the botanical meaning all of these are fruits. The development of the fruit follows fertilization, and usually the fruit does not develop perfectly in its absence, the union of the nuclei having a secondary effect in stimulating the development of the surrounding tissues in addition to the more direct effect of the production of the seed.

CLASSIFICATION OF FRUITS.

Fruits may, for convenience, be classified on several different bases, one of which is the general character of the fruit when mature. On this basis fruits are classified as fleshy and dry. Peaches, apples, and watermelons are fleshy fruits; and peanuts, the pods of the common navy bean, and the follicles of the columbine are dry fruits.

Another classification may be based on whether they do or do not split open and thus discharge their seeds. Those that split open are dehiscent fruits, and those that do not are indehiscent. The lines on which they split are sutures, and the follicles of the columbine split on one suture while the pods of beans and peas split on two, and the capsules of the castor bean on three. The capsule of the poppy is dehiscent in a slightly different way, since it discharges its seeds through pores which open near the summit. Various other methods of dehiscence are also to be seen in other fruits. Apples, oranges, and pumpkins are examples of indehiscent fruits.

A third classification of fruits is made on the basis of their origin. Those that originate from a single pistil without the incorporation of other parts are simple fruits; those that originate from several ovaries all borne in one flower are aggregate fruits; those that originate from several ovaries each belonging to a separate flower are multiple fruits; and those in which some part other than the ovary forms the main portion are accessory fruits.

SIMPLE FRUITS.

In simple fruits all of the fruit except the seeds develops from the ovary wall. All of the tissues developed from the ovary wall constitute the pericarp, the outer layer being the epicarp, the inner one the endocarp, and the middle ones the mesocarp. In fruits which are known botanically as berries all of the pericarp except the epicarp is fleshy and it forms a thin skin, the grape and the tomato being familiar examples. Closely related to the berry are the hesperidium, illustrated by oranges, lemons (Fig. 63), and grape fruits, in which the outer layer is thick and leathery, and the pepo, illustrated by the pumpkin and the water-melon, in which the outer portion is hard and is not sharply differentiated from the inner portion.

Stone fruits (drupes), such as peaches and plums, have a thin epicarp, a thick fleshy mesocarp, and a hard bony endocarp. The pit of this fruit consists of this hard endocarp with the seed contained in it. A nut has a hard pericarp usually containing a single seed, and is in many cases wholly or partially surrounded by an involucre. In the black walnut this involucre is fleshy and indehiscent and covers the nut completely. In the chestnut the involucre covers the fruit completely but is dehiscent, while in the acorn it forms a cup at the base and in the hazel nut it forms a loose husk.

A follicle (*e. g.*, larkspur) is composed of a single carpel and dehisces by a single suture on the inner (ventral) side. A legume (*e. g.*, bean, and *Laburnum,* Fig. 57) is composed of one carpel, and dehisces by two sutures, while a capsule is composed of several carpels and dehisces by several longitudinal sutures as in St. John's wort and the rhododendrons, or opens in other ways as in the poppy, which opens by pores, henbane (*Hyoscyamus*) which opens by a lid, and the snapdragon which opens in an irregular manner.

In a samara the pericarp grows out into one or more wings. The elm fruit has a wing all around, the ash fruit has an elongated wing at one end, and the maple fruit (Fig. 65)

consists of two parts each having a large one-sided wing. An akene is a small, dry, indehiscent, one-seeded fruit such as that of the buttercup or the dandelion (Fig. 54). A carpyopsis is a grain such as that of corn or wheat in which the pericarp is so closely adherent to the single seed that it is not readily separated from it.

AGGREGATE AND MULTIPLE FRUITS.

Aggregate fruits are illustrated by blackberries and raspberries, and the units making up such a fruit are berries in the botanical sense, though the whole fruit is commonly called a berry. In the true raspberries the fruit, when ripe, separates from the receptacle, while in the blackberries the ripe fruit is adherent to the somewhat fleshy receptacle. Multiple fruits are illustrated by the mulberry and the pineapple.

ACCESSORY FRUITS.

Parts other than the ovary which sometimes form conspicuous parts of fruits are the receptacle, the calyx, the style and the bracts. The strawberry consists of the developed and enlarged receptacle with the small seed-like akenes (the products of individual ovaries) embedded in small pits on its surface. The stem tissues of this fruit can be seen in a longitudinal section. The fruit of the fig consists of the hollow receptacle which has become fleshy and contains the numerous akenes within it. The apple (Fig. 64) is a pome and is composed mainly of the receptacle. When the apple is cut in two lengthwise the vascular bundles can be seen as a curved line extending from the base to the top. These vascular bundles are called the core line and the fleshy portion outside of this line is the cortex of the receptacle, while the fleshy portion extending from the core line to the parchment-like endocarp consists of the pith of the receptacle. The seeds are contained within this endocarp and the other parts of the pericarp are inconspicuous in the mature fruit. The fruits of gooseberries and currants also consist largely

of fleshy tissue produced by the receptacle. In these fruits the receptacle tissue blends with the fleshy tissue produced by the carpels so that the line between them cannot be seen in the mature fruit. In the cranberry the calyx tube is permanently incorporated with the carpels and thus forms the outer part of the mature fruit. In the fruit of clematis the style persists as a long, hairy, tail-like process.

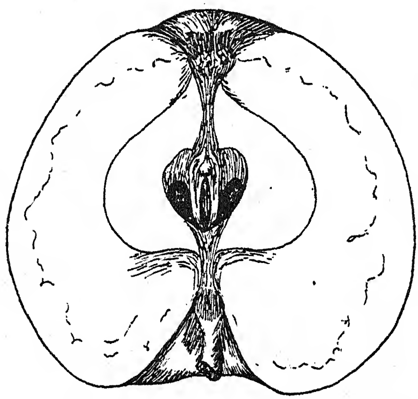

FIG. 64.—Longitudinal section of an apple. Woody tissues extend through the apple from the stem at the base to the old calyx lobes at the top. The two curved lines enclosing the somewhat heart-shaped area represent the vascular bundles of the receptacle from which the flesh of the apple was formed. Within this is the pith and outside is the cortex. The shaded areas at the center indicate the parchment-like portions developed from the carpels, and within this are shown two seeds. (Drawn by M. W. Phifer.)

GYMNOSPERM FRUITS.

The term fruit as ordinarily employed botanically includes the seed-containing structures of the junipers and the yews as well as of the pines and other cone-bearing trees. In the junipers it is a blue, berry-like structure composed of three scales (carpels) which have become fleshy and have fused, thus enclosing the seeds. The mature fruit of this tree thus suggests an angiosperm fruit rather than that of a gymnosperm (see p. 280) but the early stages of its development clearly indicate its gymnosperm nature. The fruit of the

yews is also berry-like in general appearance but consists of a single bony seed with a pulpy ring around its base which originated from the carpel and does not completely cover the seed, and the gymnosperm character of the fruit is thus evident. In the pines and their near relatives the fruit is a woody cone (Fig. 130) with naked seeds on the inner face of each scale (carpel). In most of the common conifers (*e. g.*,

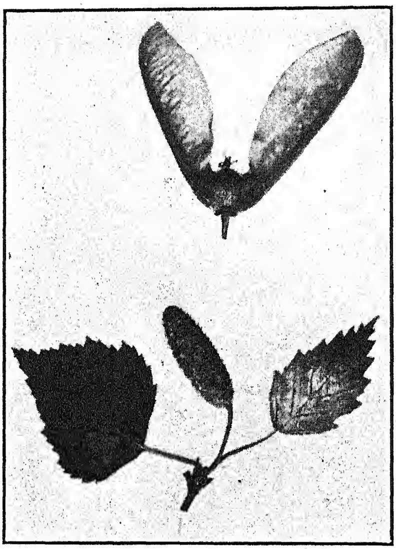

FIG. 65.—Upper, a winged fruit (double samara) of maple. Lower, a maturing pistillate catkin and two leaves of birch.

pines, spruces, and firs) there are two seeds to each scale, but in some others (*e. g.*, cedars and junipers) the number varies and there may be as many as twelve. There is a bract just below each scale, but in many of the conifers this is small and is completely hidden in the mature cone by the overlapping scales, and in some genera it is completely fused with the scale. In the Douglas fir (Fig. 130) the bract is conspicuous in the mature cone.

SEED DISPERSAL BY FRUITS.

Fruits are often of such a nature as to insure the wide dispersal of the seeds which they contain. The fruits may be dispersed by wind, water, animals, human beings, or by special devices possessed by the fruit itself. Among the fruits dispersed by wind are those of the maple (Fig. 65), the ash, the dandelion (Fig. 54) and the cat-tail. The first two produce wing-like outgrowths and the last two have a tuft of hairs on each fruit. Fruits of various species of dock (*Rumex*) have corky outgrowths which enable them to float, and many other fruits not provided with special devices will float for considerable distances. Cockleburs, beggar ticks and other fruits are carried by sticking in the tails of horses and cattle and in the fur of other animals. Many berries are eaten by birds or other animals and the seeds pass through the digestive tract without injury. The various activities of man scatter fruits widely over the earth and result in the germination of seeds in unexpected places. Special devices of the fruits themselves which result in seed dispersal are illustrated by the twisting pods of the vetches and the Scotch broom which throw their seeds some distance, and the squirting cucumber which ejects its seeds forcibly.

Suggestions for Further Reading.

The books listed under Chapter I.

PART II.

THE FUNCTIONS OF PLANTS.

CHAPTER VIII.

WATER RELATIONS.

THE NECESSITY FOR WATER.

THE presence of water in the cells is essential to all plants. The statement holds for animals also but we are here concerned with the situation in plants. Water is a large factor in the maintenance of form. Soft herbaceous plants wilt and droop if they lose too much water, and the leaves of many woody ones do the same. These changes in form following the loss of water result from the tendency of the individual cells to soften or even collapse as they lose water. The firmness of a living cell when its vacuole is full of water may be compared to the firmness of a tire when it is full of air. When a cell has little water in its vacuole it becomes soft just as a tire does if it is underinflated.

Water is necessary for the maintenance of the physical condition of protoplasm, and changes which may finally result in death follow the excessive loss of water from it. Water is a raw material for the manufacture of foods such as sugars and starches in plants. It functions also as a solvent for solids and gases and as a medium for exchange of these between the various parts of the plant.

The quantity of water in living plants is large. Green wood commonly contains from 40 to 50 per cent and in some

cases 70 per cent or more; even air-dried wood usually contains from 8 to 16 per cent; potato tubers are about three-fourths water; and the soft parts of rapidly growing plants often contain 90 per cent or more of water.

The water in the plant is mainly in the cells. In living cells it is imbibed in the cell walls, and also forms a large part of the protoplasm and a still larger part of the cell sap in the vacuole. In dead cells such as those making up the conductive portions of the xylem of vascular bundles it is imbibed in the walls and may also fill the lumen within.

THE INTAKE OF WATER.

In ordinary plants water is taken from the soil through the roots and then moves up the stem to the leaves and other soft parts, where much of it is lost by evaporation. Substances dissolved in the soil solution commonly enter the plant in the form of molecules or ions (see p. 136). These substances are largely inorganic such as potassium nitrate, though organic substances undoubtedly do enter the plant from the soil.

The entrance of water into roots is greatly facilitated by the presence of root hairs (Fig. 42). Their large exposure of surface enables them to make contact with many more soil particles than could be reached without them, and their ready adjustment of form to the shape of the soil interstices into which they grow makes these contacts intimate.

Water enters the cell walls by imbibition, which is the process of the intake of liquid by a solid having no visible pores. This process is illustrated by the swelling of dried starch grains or of a piece of dried gelatin when placed in water. It is also illustrated by the increase in size of a small cube of dry wood when placed in water, though in this case some of the water may enter the lumen of the cells and vessels or even any intercellular spaces present. In all these cases imbibition results in an increase in weight as well as in size. Imbibition produces a measurable force, as is illustrated by the breaking of a bottle when filled with dried peas or beans and placed in water for a few hours, or by

apparatus arranged so that seeds lift a weight as they imbibe water.

The movement of water from the cell wall to the protoplast is usually explained as being due to osmosis. The process in this case consists of the movement of a liquid (water) through a membrane on the two sides of which are solutions of different concentration, the membrane being permeable to the liquid (solvent), but not to the dissolved substance (solute), and the movement of the liquid being to the solution of greater concentration. A concentrated solution contains a relatively larger proportion of the solute than a dilute one does. It follows from this that a concentrated solution contains relatively less of the solvent than does a dilute one. For example, a concentrated solution of common salt in water contains proportionately more salt and less water than a dilute one does. When water moves by osmosis, it goes from the solution in which its molecules are more abundant (the less concentrated one) to the solution in which its molecules are less abundant (the more concentrated one).

A membrane permeable to the solvent and not to the solute is called a semipermeable membrane. In much of the experimental work on osmosis it has been found that the membranes used are not strictly semipermeable, but are slightly permeable to the solute. In such cases the use of the expression differentially permeable leads to clear thinking more than does the expression semipermeable. When water enters the protoplast, the plasma membrane (see p. 25) at its outer surface may be considered as the differentially permeable membrane, the solution in the vacuole and the protoplasm being the more concentrated one, and the solution in the soil and the cell wall the less concentrated one. So long as the concentration is greater inside the cell and the plasma membrane is impermeable to the substances in solution, water will continue to move into the cell until it is stopped by turgor pressure from within.

A few experiments will help to clarify our notions of this movement of water. When a concentrated solution of cane sugar is placed in a fold of beef bladder and the fold placed so that the outside is in contact with water, the water will

osmose into the sugar solution. This movement may be made more evident by fastening the bladder over the large end of a thistle tube, putting the sugar solution into the tube, placing the large end of the tube in water and leaving its upper end in air. The liquid will rise in the tube due to the osmosis of the water through the bladder into the sugar solution. In this case the bladder is a differentially permeable membrane, being very permeable to the water but very slightly, if at all, to the sugar.

Plasmolysis experiments (see p. 28) illustrate the movement of water out of plant cells when the bathing solution is more concentrated than the solution inside the protoplast. Plasmolysis of the cells of living roots may occur if they are placed in a concentrated solution. The entrance of water into a tissue and the loss of water from it may be illustrated by using two slices from a potato tuber, placing one in a concentrated salt solution and the other in tap water. The slice in the tap water swells and becomes very firm because of the entrance of water, while the one in the salt solution becomes soft due to the loss of water.

These three experiments all illustrate the movement of water through a membrane from a less concentrated to a more concentrated solution, when the membrane is much more permeable to the water than to the dissolved substance or substances. Such a movement of water may take place from pure water into a solution or from one solution into another when there is a difference in concentration, and may take place when there are different solutes present in either or in both solutions. We might, for instance, have such a diffusion of water taking place with a solution of common salt on one side of the membrane and of cane sugar on the other.

The tendency of water to osmose into a solution is dependent not only on the concentration, but also on the extent to which the solute is ionized. The osmotic pressure of a solution is due to the total number of molecules and ions present per unit of volume. Such substances as cane sugar and grape sugar form few if any ions in solution, while such substances as common salt and potassium nitrate are largely ionized

so that both molecules and ions are present in water. Ions bear electrical charges and may be composed of one element or of a group of elements. A molecule of sodium chloride (common salt) dissociates into one sodium ion (Na^+) bearing a positive charge, and one chloride ion (Cl^-) bearing a negative charge, while water yields some hydrogen ions (H^+) and some hydroxyl ions (OH^-). Potassium nitrate forms some potassium ions (K^+) and some nitrate ions (NO_3^-). It thus must be remembered that the total effect of any substance in influencing the diffusion of water into a plant or out of it will depend on the particles in solution (total number of molecules plus total number of ions) and that in Nature such movements of water are commonly due to the presence of several substances in the solution outside the cells as well as in the solution inside the cells.

Substances dissolved in soil water or in the bathing solution of submerged plants may move into the plant independent of water movements if the plasma membrane is permeable to them, so long as the concentration of the substance is less in the cell than in the bathing solution. The diffusion of a dissolved substance into a cell may take place as a movement of either ions or molecules.

THE LOSS OF WATER.

Transpiration is the loss of water from plants in the form of vapor. This loss occurs quite largely from the leaves because they expose a large amount of surface in proportion to their bulk. Water may be lost in vapor form, however, from any part of the plant and very commonly is so lost from stems, flowers, and fruits.

Water may also be lost from the plant in liquid form. When lost from uninjured surfaces, such as certain points on the margin of a nasturtium leaf, or the tips of the leaves of young wheat plants in a saturated atmosphere, the process is called guttation. When water is lost from the breaking or cutting of water-conducting organs as in the stem of a maple tree, the process is known as bleeding. Water, together with certain dissolved substances, may also be given

off from the glands of plants in the process of secretion or excretion (see Fig. 66).

To a certain extent transpiration may be regarded as a physical process comparable to the loss of water from any other moist object, such as a towel. This is true, however, only so far as the relation to external conditions is concerned. It does not hold so far as the structure of the leaf and the structure of the towel are compared.

Among the external factors influencing the rate of transpiration are the relative humidity of the atmosphere, the temperature, and the movement of the atmosphere as in winds. Relative humidity may be defined as the per cent of moisture that the air contains at any given temperature, compared with the amount of moisture that it would contain at that same temperature if it were saturated. It is evident that if the relative humidity of the air is high it will tend to make the transpiration low, while if the relative humidity is low, other things being equal, the transpiration will be high.

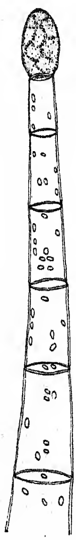

FIG. 66. — A glandular hair of *Petunia*. (Drawn by E. T. Bodenberg.)

Wind is a large factor in the rate of transpiration. When water evaporates from the leaves of a plant the relative humidity of the surrounding air is increased. If this moisture-laden air is carried away by the air movement and replaced by drier air, of course the rate of transpiration will be increased. This will account for the well-known danger of hot dry winds to crop plants such as corn.

In contrast with these external factors which have just been discussed we may consider internal factors, which include all the factors present within the plant itself. Among the internal factors will be the thickness of the leaf, the character of the leaf surface (smooth or hairy), the structure of the mesophyll, and the number and distribution of the stomates. It is evident, of course, that transpiration will tend to be much lower in a

very thick leaf, like that of stone crop (*Sedum*), than it will be in a very thin leaf, like that of dandelion. It is also obvious that a very hairy leaf (*e. g.*, mullein) (Fig. 144) will have low transpiration as compared with that of a very smooth leaf (*e. g.*, skunk cabbage or trillium). Water is evaporated from the surface of the mesophyll cells into the intercellular spaces and the amount of cell surface exposed to these spaces will influence the rate of internal evaporation in the leaf.

Factors other than the thickness of the leaf or the nature of the surface may, of course, be important in influencing the rate of transpiration. It is never safe to assume that a thin leaf will evaporate more water in proportion to its bulk than a thick one, or a smooth leaf more than a hairy one unless we know how all of the factors operate. Among the factors that must be considered are the internal structure of the leaf, the amount of colloidal water-holding material in it, and the opening and closing of the stomates.

The stomates have a great influence on the amount of transpiration. If they are equally distributed on both surfaces, where the sun and wind can have free action on the upper surface, the transpiration will probably be higher, other things being equal, than if most of the stomates are on the lower surface where they are frequently protected from the heat of the sun and somewhat from the effects of the wind. In addition to the number and distribution of the stomates, the opening and closing of the stomates is a factor in the rate of transpiration. It is found that, in general, stomates tend to open during the day and to close at night, although all factors in any given case must be considered before arriving at a conclusion in regard to this opening and closing.

The amount of water lost from leaves by transpiration is very large. It has been estimated from reliable data that an old apple tree loses about 18 gallons of water per day and that a single sunflower plant loses about 17 gallons per season. This is water which has been absorbed in liquid form from the soil.

Transpiration has several interesting effects on the plant. One of these is an accumulation of mineral matter in the

leaves. As the water evaporates the mineral matter is left behind, and this accounts for the high ash content of leaves. This accumulation of mineral matter in leaves is one of the reasons why leaves are a valuable constituent of compost used in enriching soil. Another effect of transpiration is the cooling of the leaf. If a drop of some volatile substance like ether is allowed to evaporate on the hand, a very cool sensation is produced. Water is very much less volatile, but still its evaporation does result in cooling the surface from which it evaporates. It is believed by some plant investigators that if it were not for the cooling effect of transpiration the plant would die from the excessive heat caused by its respiration.

Transpiration is thought by some workers to be harmful to the plant rather than beneficial. It is true that plants may be killed by transpiring water more rapidly than they can take it in from the soil, and the view that transpiration is a danger to which the plant is exposed because of the structures that make the exchange of gases in photosynthesis and respiration possible has considerable support. Among the good effects that transpiration has been thought to have are: (1) that it cools the leaf, and, (2) that it facilitates the intake of mineral nutrients from the soil and their upward movement to the leaves. The present state of knowledge scarcely warrants firm belief that transpiration is wholly good for the plant or wholly bad for it, and it is best to consider all the facts with an open mind.

THE RISE OF WATER IN PLANTS.

It is well known that water reaches the tops of tall trees, some of which are 300 feet or more in height. It takes considerable energy to raise water to this height, and this energy requirement and the mechanics of the movement of the water through the plant are very important questions. We know that most of the water enters the roots through the root hairs, travels through the root cortex into the vascular tissues, thence through the vascular tissues of the root, stem, and branch into those of the petiole of the leaf and from there

into the veins of the leaf, from which it passes into the mesophyll cells.

Water is continuously entering the roots and being given off at the surface of the leaves, and it seems probable that transpiration plays an extremely important rôle in this upward movement of water through the stems. As water is transpired from the mesophyll cells of the leaf a water deficit is produced and more water moves in to replace the loss. As water is lost from the walls of the mesophyll cells it is continuously replaced from the protoplasts and is thus drawn from cell to cell and is finally drawn from the supply in the vascular tissues of the leaf. Evaporation, acting through imbibition and osmosis, will thus tend to cause water to move up through the lumen of the vessels or tracheids. It seems probable that since there is considerable molecular cohesion in water, and since water is continuous throughout the plant, evaporation from the top of this column lifts it up. It is readily demonstrated that the cohesive force of a column of water is amply sufficient to stand all the strain involved in this process and that both imbibition and osmosis are capable of taking their part in all the exercise of force that is necessary to lift this water. Osmosis and imbibition (see pp. 134–135) would, of course, act in the root in the entrance of water as well as in the loss of water from the leaf.

The general concept of the manner in which water moves up tall plants just outlined is given fully in the two volumes by H. H. Dixon (Nos. 2 and 3) listed at the end of this chapter.

It should be said, however, that some workers believe that water is moved up the tree by the pumping action of living cells, a view which is quite in contrast with the one just outlined. This view is fully set forth in the volume by J. C. Bose listed below.

Suggestions for Further Reading.

1. Bose, J. C.: Physiology of the Ascent of Sap, London, 1923.
2. Dixon, H. H.: Transpiration and the Ascent of Sap in Plants, London, 1914.
3. Dixon, H. H.: The Transpiration Stream, London, 1924.

CHAPTER IX

THE FORMATION AND USE OF FOODS.

PHOTOSYNTHESIS.

Photosynthesis is a process that goes on in green plants by which they manufacture carbohydrate foods from the two raw materials, carbon dioxide and water, the energy for the process being sunlight. This process may be considered from two standpoints: (1) the materials involved in the transformation, and (2) the energy transformations. We might, on that basis make two definitions, one of them emphasizing the transformation of materials and the other the transformation of energy. It seems best, however, to include both in one definition. The word photosynthesis is of American origin and came into use a little before the year 1900.

Historically our knowledge of photosynthesis has depended very much on certain advancements in our knowledge of chemistry. It was not until about the year 1800 that we began to understand the gaseous exchanges between the plant and the surrounding atmosphere. Shortly before this time Priestly had discovered oxygen, and various others had learned a great deal about oxygen and carbon dioxide and their relation to the process of burning and the process of respiration in animals.

It was shortly before this time that Van Helmont, a Flemish physician, carried on his famous experiment with a plant. This experiment is believed to be one of the very first conducted in plant physiology. He started the experiment in order to try to find an answer to the question, "what is a plant made of?" that is, "What is the source of the material in the plant?" He had seen large plants grow from small seeds and questioned how this could be. He took a willow cutting weighing 5 pounds, placed it in 200 pounds

of earth and watered it for five years with rain water. He put the leaves back on the soil. At the end of five years he found that the weight of the willow cutting had increased to 165 pounds while the soil had lost but a few ounces. He concluded therefore that a tree is nothing but transformed water. It is obvious now that his erroneous conclusion was due to the lack of knowledge of the gases of the atmosphere especially that carbon dioxide in the atmosphere is the source of a large amount of the material forming the substance of plants.

Some carbohydrates present in plants are sugars, *e. g.*, grape sugar and cane sugar; starches, *e. g.*, those found in corn, beans, and potatoes; and the cellulose which is found in the walls of many plant cells, such as those of a green leaf or a potato tuber.

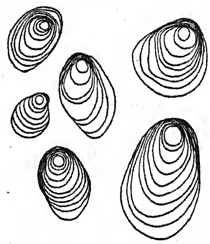

FIG. 67. — Grains of potato starch, showing hilum and laminations. (Drawn by M. W. Phifer.)

The Products. — It does not seem probable that starch is the first product of photosynthesis. It is much more probable that the simpler molecules of grape sugar or cane sugar would be formed before such complex ones as those of starch, and this view is supported by some direct evidence. It is found in some cases that when green plants are placed in sunlight, oxygen is given off for some minutes before starch is formed, and in some plants no starch at all is found though sugars are abundant. Starch is readily detected in plants because it produces a blue color with iodine and it has thus been easy to popularize it as a product of photosynthesis, but the evidence now available indicates that grape sugar ($C_6H_{12}O_6$) is the more typical early product of photosynthesis.

It seems to be well established that intermediate substances are formed and exist temporarily between the use of the raw materials, carbon dioxide and water, and the final production of carbohydrates, but there is no very definite evidence as to just what these substances are. Among the ones for which there is some evidence are formaldehyde, formic acid, and carbon monoxide. Belief in the formaldehyde hypothesis

has been rather general, but we still lack definite knowledge of the steps in the synthesis of carbohydrates.

The Raw Materials. Carbon dioxide is present in the atmosphere in the proportion of about 3 or 4 parts in 10,000 of air, which seems to be a very small amount in consideration of the importance of the process in which it functions as a raw material. The carbon dioxide in the air, of course, would have been exhausted long ago if it had not been rather constantly renewed. Among the sources from which it is being renewed are the respiration of all organisms, including both plants and animals, combustion (the burning of all kinds of fuel), and the decay of organic matter. It is also present in the gases given off to the atmosphere by some industrial processes and in the gases emitted from volcanoes. From these various sources carbon dioxide is kept at a fairly even balance with the use of it in photosynthesis.

Carbon dioxide enters the plant mainly through the leaves. It diffuses through the stomates into the intercellular spaces of the mesophyll of the leaf. There is no mass movement of air through the stomates; the carbon dioxide merely moves through them according to the diffusion gradient, from where it is more abundant to a place where it is less abundant. In the intercellular spaces of the leaf the carbon dioxide comes in contact with the moisture of the cell walls, is dissolved and thus passes through the cell wall into the cytoplasm or even into the vacuole.

Water is finally conducted from the ends of the veins into the same cells which contain the carbon dioxide, and carbon dioxide and water thus come into contact with the chloroplasts in the cells and it is there that the union of these two takes place, producing the carbohydrates.

Oxygen is given off as a waste product of this process. We speak of it as a waste product because it escapes from the plant, while we speak of the carbohydrates as a manufactured product because they remain in the plant and are eventually used there. The process of photosynthesis may be represented by the equation $6\ CO_2+6H_2O \rightarrow C_6H_{12}O_6+6O_2$.

Chlorophyll.—The green substance present in leaves is called chlorophyll. This name has been in use for a little more

than a hundred years to designate the green pigments found in plants. It is present in chloroplasts (Fig. 4), which are small green bodies in the cytoplasm of the cell. This is the condition in which it is found in all the higher plants, but there are some exceptions in the lower ones (Fig. 73).

If we grind some green leaves in a mortar with sand and a little acetone the chlorophyll readily dissolves. If the material is then filtered we get a clear solution of chlorophyll in acetone free from suspended matter. Chlorophyll dissolved in this way consists of four pigments. Two of these, chlorophyll *a* and chlorophyll *b*, are green in color; while the other two, carotin and xanthophyll, are yellow. Chlorophyll *a* and chlorophyll *b* both contain the chemical elements, carbon, hydrogen, oxygen, nitrogen, and magnesium; the chemical formula for the former is $C_{55}H_{72}O_5N_4Mg$, and that for the latter is $C_{55}H_{70}O_6N_4Mg$. They are thus very similar in their composition, differing only in the amount of the oxygen and hydrogen. Magnesium is the only metallic element contained in chlorophyll. Iron is necessary for the formation of chlorophyll, but does not form a part of the molecule. Carotin consists of carbon and hydrogen only, while xanthophyll consists of carbon, hydrogen and a very small amount of oxygen. The formula for carotin is $C_{40}H_{56}$, and that for xanthophyll is $C_{40}H_{56}O_2$. Carotin and xanthophyll are commonly known as the carotinoids, and they give the yellow color to a number of animal tissues and substances, among which are egg yolks, the shanks of chickens, the fat of many animals, and butter fat. These carotinoids pass unchanged from the plant which is used as food into the tissues of the animal.

One of the interesting and important properties of chlorophyll is its ability to absorb certain portions of the visible spectrum (Fig. 68). It is well known that if a ray of ordinary white light is thrown through a prism of glass it is broken up into the colors, red, orange, yellow, green, blue, and violet.

If this ray of white light, before being thrown through the prism of glass is passed through a small bottle of chlorophyll *a* there is a broad black band mainly in the red but extending a little into the orange. This means that part of the red and

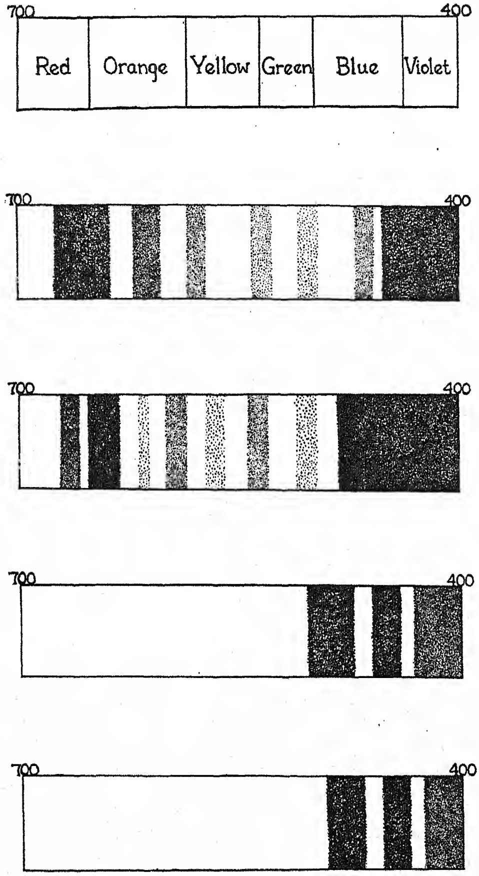

FIG. 68.—Absorption spectra of chlorophyll, carotin, and xanthophyll. Top, the position of the colors in the spectrum of sunlight, for comparison. Next, the absorption bands show when light is passed through a solution of chlorophyll *a*. The degree of absorption is indicated by the relative darkness of the bands. Next, absorption bands shown by chlorophyll *b*. Next, those of carotin. Bottom, those of xanthophyll. (Redrawn by permission from Schertz and Merz's translation of Willstätter and Stoll; drawn by M. W. Phifer.)

orange light has been absorbed by the chlorophyll and the band is called an absorption band. Chlorophyll *a* shows seven absorption bands and chlorophyll *b* eight bands. These as well as the absorption bands of carotin and xanthophyll are shown in Fig. 68.

Chlorophyll is now used in various industries and has become an article of commerce. It is used to conceal the color of some products and to give a desirable color to others. It is also used in medicine. Among the products in which it is used to conceal the color are cottonseed oil and olive oil. It is used to give color to some food products and also to other products such as stearin candles and leather. At least one form of chlorophyll is sold as a medicine and it is used in some secret preparations.

A full account of chlorophyll, carotin and xanthophyll is given in the volume by Willstätter and Stoll, translated by Schertz and Merz listed at the end of this chapter. Many of the facts presented above are taken by permission from this volume. An excellent account of carotin and xanthophyll is also given in the volume by Palmer listed at the end of this chapter.

Energy.—Experiments have indicated that the light used most efficiently is probably the light near the red end of the spectrum. It is definitely known that plants can carry on photosynthesis without either violet or ultraviolet light. Sunlight furnishes the energy which goes into the process of photosynthesis, and all carbohydrates, such as glucose, contain energy, as we can readily demonstrate by burning them and getting the energy in the form of heat, or by eating them and getting the energy shown in the various forms of bodily activity.

Carbon dioxide and water contain much less energy. It is evident then, that this process consists of the manufacture of compounds of high-energy content from raw materials of low-energy content. This means that energy is stored in the manufactured products and must get into the plant in the course of this process of manufacture. The energy, of course, is the energy of sunlight.

Sunlight is not absolutely necessary since artificial light

of sufficient intensity may be readily substituted. In substituting artificial light of suitable intensity care must, of course, be taken not to heat the plant sufficiently to destroy or injure it.

Demonstrations.—Photosynthesis can be demonstrated in several ways. One of these is by putting a water plant in water in a glass vessel or test-tube and watching the bubbles of gas which are given off from the plant when it is placed in sunshine at a suitable temperature. By placing the plant under a funnel and inverting a test-tube of water over the stem of the funnel, with its lower end under the surface of the water in the jar, the gas may be collected and it is found that it will cause a glowing splinter to burst into flame, suggesting that it is oxygen. In this case we are demonstrating the occurrence of the process by means of its by-product.

Another means of demonstrating that the process of photosynthesis has been going on is to test leaves for starch, which is one of the products of the process. If we take a potted plant and put it in the dark until its leaves are entirely devoid of starch, as shown by testing one of them by removing the chlorophyll with alcohol and applying iodine, which gives a blue color to starch, we then have a plant which we can use in the experiment. If we put this plant in bright sunlight for a few hours and then repeat the starch test on another leaf we shall find that starch is now present where it was absent before the experiment began. In this case we are judging the occurrence of the process of photosynthesis by the presence of the manufactured product.

THE FORMATION OF OTHER ORGANIC SUBSTANCES FROM CARBOHYDRATES.

Fats and oils are common in plants and are especially abundant as reserve food in fruits (*e. g.*, olive oil) and seeds (*e. g.*, castor oil). They contain the same chemical elements found in carbohydrates and the investigations that have been made indicate that they are probably formed from the carbohydrates.

Proteins are present in all plants; in fact every living cell

contains protein. In addition to the carbon, hydrogen, and oxygen found in carbohydrates all proteins contain nitrogen, and it seems probable that they are formed from carbohydrates by interaction with chemical groups containing this element.

Many other organic compounds are present in plants. Among these are glucosides, alkaloids, tannins, and anthocyanins. The first two are constituents of many plants used as drugs. Glucosides are found in bitter almond seeds and the leaves and stems of willow trees. Among the alkaloids found in plants are nicotine in tobacco, morphine in poppies, and quinine in cinchona bark. The formation of glucosides and alkaloids in plants is not very well understood, but such facts as are known indicate that they are probably formed from carbohydrates.

Tannins are astringent substances which are commonly found in many plants especially in leaves, bark, and unripe fruits. They are abundant in tea leaves, hemlock bark, and green apples. The part played by tannins in the metabolism of plants is not well understood, but it seems likely that in many cases they are waste products rather than reserve foods.

The anthocyanins are compounds capable of developing conspicuous colors such as reds and blues. In their chemical nature they are similar to the glucosides. They play an important part in the development of brilliant autumnal coloring in the leaves of oaks, maples, dogwoods, and other trees, and also the color of apples, cranberries and other fruits, and flowers, such as those of geraniums and violets.

Many volatile oils are also found in plants. They are different in physical and chemical properties from the fixed oils which were discussed above in connection with fats. Most of the characteristic odors of plants are due to volatile oils. Familiar odors due to the presence of volatile oils are those of celery, mints, wintergreen, and sweet birch.

PHOTOSYNTHESIS AND HUMAN EXISTENCE.

Photosynthesis is a process of the very greatest importance to mankind. Men would be unable to continue to live if

it were not for this process, since it is the fundamental chemical process in the manufacture of our foods from raw materials. It is easy to see, of course, that all our carbohydrate foods come directly from this process. Oils and fats, proteins, and other foods obtained from plants are manufactured by them from carbohydrates, and it is thus clear that all of our vegetable food comes from the process of photosynthesis. It is also evident that all of our animal food can be traced indirectly to photosynthesis, since animals live ultimately on plant food.

Much of our clothing can also be traced directly to this process of photosynthesis. Cotton and flax are obtained directly from plants. Such materials as wool, leather, fur and silk, are derived in one way or another from animals. To whatever extent minerals enter into the manufacture of clothing we have an exception to the generalization that clothing comes directly or indirectly from photosynthesis. In so far as our shelters are made of wood or of thatch composed of leaves or other plant parts, we are dependent upon the process of photosynthesis for shelter.

Much of the energy used in the everyday affairs of life also comes indirectly from photosynthesis. All of the materials that we use as fuel have originated from photosynthesis. Wood is traceable directly to this process, and coal to plant remains. Gasoline and kerosene are traceable through the crude oil to their origin in organic materials from either plants or animals.

RESPIRATION.

Respiration is a process which is carried on by all living things, both plants and animals. It may be defined as the oxidation of organic materials in organisms with the release of energy. Respiration in its ordinary form is accompanied by the taking in of oxygen and the giving off of carbon dioxide. The materials oxidized in the plant are probably mainly carbohydrates, and glucose (grape sugar) may be taken as a typical example of a sugar oxidized in respiration. There

seems to be no doubt that other substances, such as fats and proteins, are probably oxidized to a certain extent in the course of respiration; the carbohydrates, however, seem to be the representative substances participating in this process. The old view that protoplasm is the substance oxidized in all respiration is now not altogether tenable. Protoplasm is known, of course, to be a mixture of such substances as proteins, carbohydrates and inorganic materials, and no doubt some materials which are constituents of protoplasm are oxidized, but to consider the protoplasm as necessarily *the* respiratory material does not seem to lead to the greatest clearness of thinking on this subject.

Respiration is in many ways the exact opposite of photosynthesis. Respiration results in tearing down the material of the plant, while photosynthesis results in building it up. Respiration decreases, while photosynthesis increases the dry matter. Respiration is the oxidation of organic materials while photosynthesis is the reduction of carbon dioxide. Respiration is a continuous process, which in the main is not dependent upon light, while photosynthesis is dependent upon light, and hence is usually not continuous. Respiration liberates energy and photosynthesis stores energy in the potential form.

Kinds.—Respiration occurs in some plants in the absence of oxygen. This is called anaërobic respiration in distinction from aërobic respiration, in which free oxygen is necessary. In anaërobic respiration the molecules of respiratory material are broken down and one part is oxidized by the use of oxygen derived from the other. Energy is thus produced without the use of oxygen from any source outside of the respiratory material, and this type is often called intramolecular respiration. It is the common type in many microörganisms and occurs also in some higher plants.

Demonstrations.—Respiration has been demonstrated and measured quantitatively by various devices. Much work of this kind has been done on seeds, tubers, roots, and fungi because in these photosynthesis is absent and it is easy to get data on respiration. Green plants may, of course, be used if they are placed in darkness where photosynthesis is stopped.

Respiration has been studied by measuring the amount of carbon dioxide lost. This is very frequently done by drawing the air, after it comes from the leaf, through barium hydroxide, or calcium hydroxide. By this means a chemical computation of the amount of carbon dioxide given off is readily made. Another way of demonstrating or measuring respiration is by measuring the amount of oxygen used. Some interesting pieces of apparatus have been devised for measuring both of these substances.

Products.—The products of respiration in the main are carbon dioxide and water, but in some succulent plants, such as in the large cacti, and in some of the fungi, it has been found that organic acids are produced instead of carbon dioxide.

The oxidation of glucose to the final products, carbon dioxide and water, may be represented by the equation $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$.

Much energy is set free in the plant by respiration. Some of this energy is lost from the plant to its environment, just as heat is lost from any warm object to the air. Some of the energy is used in the evaporation of water from the leaf and some of it is used by the plant in the various processes of metabolism.

Respiration and Enzymes.—Respiration is promoted by the action of enzymes (see p. 154). These are organic substances produced in organisms and having the power to promote chemical activity. The action of the enzymes involved in respiration is rather complex and there is some difference of opinion as to just how they operate. It seems probable that the action of at least one of them results in the production of free oxygen from certain organic compound in plants and that this free oxygen then acts on the respiratory materials.

Factors.—Among the factors in respiration are light, heat, water, oxygen, wounds, poisons, organisms, and hydrogen ion concentration. Light usually increases respiration, possibly because of the increase in the openings of the stomates, thus allowing more carbon dioxide to diffuse out and more oxygen to diffuse in. It is possible also that light

increases respiration by increasing the ionization of the atmosphere, thus resulting in greater chemical activity. Heat has been found to be an important factor in the rate of respiration as it is in many other processes of metabolism in plants. Heat is an important factor in chemical processes and the processes of metabolism in plants are, to a considerable extent, chemical. Wounds and poisons have been found in many cases to stimulate respiration. Anesthetics were found to increase respiration in a large kelp (*Laminaria*) and such poisons as cyanides have also been found to increase respiration in other plants. The oxygen supply, of course, is a factor in ordinary respiration, but there is enough of it present in the atmosphere ordinarily so that a slight decrease would not be serious. It has been found in many cases that diseases caused by organisms cause an increase in the rate of respiration. This has been shown in the case of diseased apple bark, and in the case of leaf curl of potatoes, the mosaic disease of tobacco, and a number of other diseases.

By hydrogen ion concentration we mean what may commonly be expressed as the acidity or alkalinity of the tissues (see p. 352). The question of whether the tissues are acid or alkaline has been found to be very important in connection with respiration; hydrogen ion concentration undoubtedly is an important factor in the rate of this process.

DIGESTION.

Digestion is essentially much the same process in plants that it is in animals. It may be defined as the transformation of foods by the aid of another substance from an insoluble to a soluble form, or from an indiffusible to a diffusible form. In a wider sense it is a change of one food into another. A common example of digestion in plants is the transformation of starch, an insoluble and indiffusible substance, to dextrose, which is soluble and diffusible. Although digestion in plants is essentially the same as in animals, there are some differences to be considered. Digestion in the higher animals takes place in highly differentiated

organs, while even in the higher plants this is not the case, there being very rarely any specialized tissues for digestion. In simpler animals, such as the protozoans, which are one-celled, we have more analogy to the kind of digestion in simple plants, but in the higher plants the lack of digestive organs constitutes a striking contrast to the specialization in the digestive organs of the higher animals.

In the definition of digestion previously given it was stated that other substances are involved in the transformations of the food to the soluble and diffusible form. These other substances are the enzymes. We know enzymes very largely by their effects; we can readily make water extracts from plants which bring about the changes, and we call such extracts preparations of enzymes. As an example of an enzyme we may take diastase (amylase), which accomplishes the digestion of starch to sugar. This enzyme can be readily extracted from such plant tissues as a potato tuber or sprouted barley, and may be allowed to act upon starch. The steps in the progress of the change from the starch grains to a soluble sugar can be readily followed. Other enzymes which are commonly present in plants are inulase, which changes the inulin of a dahlia tuber to a soluble sugar, and cytase, which changes the hemicellulose present in certain cell walls to such sugars as mannose and galactose.

Other enzymes in plants are lipase, which brings about the digestion of fats; and papain, present in the pawpaw, which effects the digestion of proteins.

It is evident, of course, that starches, fats, and other substances must be digested before they can be built up into tissue. Tissue building is not possible from insoluble or indiffusible substances.

Suggestions for Further Reading.

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CHAPTER X.

GROWTH AND MOVEMENT.

GROWTH.

INSTEAD of considering the functions of a plant as individual functions we may look at the effect of all the functions and processes, considered together, upon the plant as a whole. In this chapter we study the way plants grow and move as a final result of all the various processes and functions which we have previously studied such as imbibition, osmosis, transpiration, photosynthesis, respiration, and digestion. We here consider all of them as working together within the living plant and coördinating in its development.

A plant in the course of its life goes through what is called the grand period of growth. There will, of course, be fluctuations in the growth rate, but in general, there is a gradual increase in the rate of growth from a very slow start, reaching a maximum, then falling off and finally ceasing. In the case of a bean plant it was found that on the first day the growth rate was 1 millimeter; on the second day it was $1\frac{1}{2}$; the third, $2\frac{1}{2}$; the fourth, $5\frac{1}{2}$; the fifth, 7; the sixth, 9; the seventh, 14; the eighth, 10; the ninth, 7; and on the tenth day, 2.

In the growth of organs from meristematic tissue three stages are evident—formation, enlargement, and differentiation. Certain changes resulting in maturity also occur in connection with differentiation. Cells are formed by the division of other cells and those gradually enlarge and soon begin differentiation into the various tissues that make up the organ. In stem tips (Fig. 37) and root tips primary growth thus forms such tissues as xylem, phlœm, cortex, and epidermis. In secondary thickening in stems and roots the activity of the cambium (Fig. 27) leads by these three stages

to the formation of xylem and phlœm. In the leaves of higher plants the growing region is general and not confined to a definite place as in stems and roots, but the stages of growth are the same.

Growth from an apical cell (*e. g.*, the mosses) shows these same stages but the amount of differentiation is in many cases less than that in plants growing from a group of initial cells (meristem), and the term maturation may be appropriately used for the third stage instead of differentiation. In the roots and stems of ferns, however, growth takes place from a single apical cell at the tip of each branch and is followed by differentiation into distinct tissues. Growth in many of the lower plants (*e. g.*, *Spirogyra*) is not localized at all and every cell may divide and form new ones. The three stages—formation, enlargement, and maturation are evident in these plants also.

External Conditions.

There are certain conditions which are necessary for all growth. These are called the formal conditions and among them are water, heat, nutrients, and oxygen. All of these and some others are factors in the growth rate. The external conditions influencing growth will be discussed in the following order—temperature, light (intensity and wave length), gravity, nutrients, water, and oxygen.

Temperature.—In investigating the effect of temperature on growth it has usually been found that for each species there is a definite optimum at which the plant grows best, a minumum below which growth ceases, and also a maximum above which growth ceases. It is well known, of course, that ordinary plants grow fairly well at the temperature of living rooms, although the best growth is usually obtained when the temperature is a little above room temperature. In investigating the minimum temperatures at which plants grow, great variations have been found. Some of the Arctic algæ grow at almost the freezing point. Some of the beans have been found to germinate at temperatures above 45° F.,

but not below that point. The bacillus of tuberculosis does not continue growth below 98° F.

In considering the maximum it has been found that some of the algæ grow in springs which are too hot to hold the hand in with comfort. Land plants ordinarily do not grow well much above 100° F. though some of the succulent plants grow well at higher temperatures.

Light.—Different plants grow under very different light conditions. Ordinary weeds, such as grow by the roadside, flourish well in full sunlight, while many of the ferns grow only in shaded places. Shading is resorted to in the growth of such plants as ginseng and, in some cases, tobacco.

It has been found that plants grow best in ordinary white light rather than in light of any special color. Many plants will grow with only a portion of the spectrum and some special points in the growth may be improved by colored light, but in general, ordinary white sunlight comprising all the wave lengths of the spectrum (Fig. 68) is best.

Plants grown in the absence of light usually do not develop green color but appear somewhat yellowish. In addition to this these etiolated plants show certain changes in form and structure. There is usually a tendency to elongate the internodes of the stem, and the petioles of the leaves. The leaf blades of etiolated plants are usually small and undeveloped, and there is a general tendency for the leaf tissues and organs to remain in an embryonic condition.

In etiolated plants the mechanical tissues are generally very much reduced, hence the stem is likely to be soft. The greater growth in length is correlated partially with the development of longer cells and partially with the production of a greater number of cells.

The direction of light is a very important factor in the form that the plant assumes. It is well known, of course, that many plants turn toward the light. In addition to this, however, there are certain effects of light on developing cells which are important. In the first division of the egg of *Fucus* it has been found that the direction of the light determines which of the first two cells shall produce the cells which will eventually form the thallus and which one will

produce the first rhizoids. Incidentally, it is interesting that this same polarity has been also determined by the electric current.

In some cases it has been found that when an undifferentiated group of cells, such as that found in the gemmæ of *Marchantia,* are exposed to light from one direction, the direction of the light will determine which of the cells will develop into the upper (dorsal) portion of the thallus, and which will produce the lower (ventral) surface.

Gravity.—Gravity is an important factor in growth. It acts continuously on all plants and its direction is constant, but plant organs may be placed in different positions with reference to its line of action, and considerable changes often result from such a change of position. It has been found that the stamens and pistils of the flowers of one species of *Amaryllis* occupy a different position with reference to the other parts of the flower when the developing flower is turned downward from what they do when the flower bud opens in an erect position. The form of some plants can also be changed by rotating them on an instrument called a clinostat so that gravity acts on all sides of them instead of on one side only. The position of the spore-bearing parts of a gill fungus has been changed by this means.

Nutrients.—Differences in the amount of various nutrients in the soil often result in differences in the form of individuals of the same species. Many plants tend to grow tall when nitrogen is abundant. The relative vigor of vegetative growth and fruit production in apple trees is much dependent on the relative amount of nitrogen supplied to them and of carbohydrates produced in them. Calcium is also experimentally shown to be a large factor in the growth of wheat seedlings.

Water.—The form of many plants is different when grown where water is abundant from what it is where it is scarce. The relation of moisture to the growth of plants is discussed under Ecology (pp. 344, 348).

Oxygen.—The influence of oxygen on growth is seen in many cases. The common bread mold shows differences in form depending upon the amount of oxygen present, and

many microörganisms do not grow at all in the presence of free oxygen, while others do not grow in its absence (see p. 212).

Internal Conditions.

Correlation.—It has been found that the organs of a plant work together more or less harmoniously in the growth, development, and nutrition of the plant. This working together is usually spoken of as correlation. Correlation may be defined as the control of the amount and character of growth in one part of an organism by another part or parts.

It is found, for instance, in the case of the scarlet runner bean that the growth in the early stages of the plant is continued from the stem tip, the buds in the axils of the leaves remaining undeveloped. If, however, the stem tip is cut off, it is found that the two lateral buds nearest it will immediately begin development and usually one of these will finally produce a stem which will take the place of the stem tip that was removed.

A somewhat similar condition is found in many coniferous trees, such as the Douglas fir and the spruce. After a few years a young tree which has had its terminal bud removed may show only a very slight curvature or scar to indicate where the old stem was removed and the new growth from the lateral bud occurred.

There are many tissues in plants which in the ordinary course of the growth of the plant never develop further, but which, if given a chance because of the removal of the inhibiting part, will develop into plant organs. When a tree, such as a cottonwood or willow, is cut down, new growth, or regeneration, will take place from the old stump. This usually does not take place from coniferous stumps, though the redwood (see p. 286) is an exception.

We have very little definite information to indicate just what is the nature of the control of one part by another in correlation. Much study has been given to this subject and a number of theories have been suggested but none of them seem to have been fully established. It is believed by a good many workers that nutrition is in some way a very

direct factor in the development, but this does not seem to explain fully all cases. Another theory is that parts where metabolism is active exercise some sort of control over other parts where it is less active. It has also been shown that there is a difference in electrical potential in some cases between young, actively growing regions and older regions

FIG. 69.—Regeneration of pale laurel (*Kalmia polifolia*) after the upper portion had been burned off.

where growth is less active, and it is suggested that the mechanism of correlation may be connected with this difference. A view held by many workers is that a complex of many factors determines in each case whether growth shall occur or be restrained in any particular portion of the plant, and that the explanation of correlation is to be sought in a study of this complex of factors.

It seems certain that the harmonious development of all parts of a plant is due to the restraining influence on some parts by others, and that when the balance is disturbed new lines of development follow. We do not, however, understand just how this influence is exercised. The plant evidently is a bundle of potentialities; what it develops into depends partly upon its environment and partly on whether any of the parts of the plant are artificially removed, or their activities inhibited by some means.

Periodicity.—Many plants undergo a somewhat regular periodicity in their growth and development. Periodicity may be defined as activity followed by rest. Of course, death follows eventually in the normal course of events in most cases. In the case of perennial plants, however, the alternate periods of activity and rest occur many times before death comes.

In the case of unicellular plants which reproduce by fission only, there apparently is no normal provision for death, that is, death does not seem to be a part of the regular cycle. It may come by accident but not in the course of what we ordinarily call old age.

The periodicity which we most ordinarily think of is the yearly periodicity in which plants grow rapidly in early spring, continue active during the summer, and go into a dormant condition with the coming of winter. There is also, of course, a daily periodicity, which may be associated partly with changes in light, heat, and moisture. Some plants show a periodicity tending toward the production of blossoms and leaves at quite unusual times of year and in some plants periodicity is largely absent.

It has been found that periodicity may be readily changed. Plants which ordinarily bloom in the spring may be made to bloom in winter by bringing them into the greenhouse and keeping good growing conditions of temperature and moisture. In many such cases, however, plants that are normally subject to hard winters will bloom more quickly in the greenhouse in winter if they are allowed to freeze first.

It has been found within the last few years that length of day is a very important factor in the periodicity of plants.

The length of day has been artificially shortened in these experiments, and some plants which normally bloom in the shorter days of late summer were thus made to bloom in midsummer. The soy bean is an example of this. Other species do not behave in quite the same way, however, and no broad generalization can be made.

Periodicity might be regarded as something inherent in the plant or as something which is the result of the interaction of external factors. So many cases have been found in which the rhythm can be experimentally changed that it seems probable that the interplay of external factors rather than an "inborn" rhythm is the cause of most cases of periodicity.

MOVEMENTS.

Locomotion.—Movements occur in many plants. This may be a movement of the whole plant from one place to another (locomotion), or it may be a movement of one or more of the organs while the plant as a whole remains fixed. Locomotion occurs among simple plants such as the diatoms, and bacteria (Fig. 92), and in organisms such as the flagellates (Fig. 72) which possess both plant and animal characters. Locomotion is common also among spores and gametes, as is illustrated by the zoöspores and the gametes of *Ulothrix* (see p. 185) and the sperms of the mosses. In all these cases locomotion occurs in water, and in all cases except the diatoms it is accomplished by means of whip-like processes, called flagella in some of the organisms and cilia in others. There have been several suggestions as to how diatoms move but we have little definite knowledge about their means of locomotion.

Locomotion may appear to be undirected as in the movements of bacteria and flagellates when they are mounted in water and viewed under the microscope, or it may be determined by differences in light intensity on different portions of the medium or by differences in the concentration of dissolved chemical substances or of oxygen or other gases in the medium. Directed locomotion is called taxic movement, and each taxic movement is named according to the

cause of the movement. Thus, locomotion due to light is phototaxy; that due to chemicals is chemotaxy, and that due to gases in the medium is aërotaxy.

Stimulated Movements of Organs.—Many movements of plant organs occur in response to external stimuli as is illustrated by the sensitive plant (*Mimosa*) when the whole leaf droops and the leaflets fold together in response to the contact of some object with the leaf. Gradual recovery occurs after a few minutes so that the leaf and the leaflets again assume their normal position. In this case the movements, both of response to the stimulus and of recovery afterward, are due to changes in the water content of the cells of a swollen portion (the pulvinus) at the base of the whole leaf and of each leaflet. Changes in permeability allow water to move from the cells of the pulvinus into the intercellular spaces and from these spaces into the cells, and the movement is thus brought about by turgor changes.

The word stimulus as used in plant physiology may be defined as a change in the intensity of some factor in the environment or a difference in the intensity of some factor in different portions of the environment. Mechanical contact is thus a stimulus because the intensity changes from zero to a positive quantity, and an increase in the light intensity on one side of the plant is a stimulus because it creates a difference of intensity in different portions of the environment. A change of light intensity all around the plant is also a stimulus, though it may result in changes in the rate of growth rather than in the movements of organs. The use of the word stimulus in plant physiology can lead to clearness of thinking only when it is interpreted as meaning some definite condition in the environment and an effort is made to understand the way in which the stimulus brings about the results that are observed.

Direction of Growth.—The direction in which the organs of many plants grow is due to external stimuli, and curvatures are often produced by these. Such phenomena are known as tropisms and each is named according to the stimulus which causes the organ to grow in that particular direction. The stems of plants commonly grow erect in response to the

influence of gravity, and if a plant is placed in a horizontal position the stem tip, or in some cases, even a large portion of the stem curves to an erect position.

The control of the direction of growth in stems by gravity is called geotropism. The influence of gravity is seen in the erect position of the stems of herbs, shrubs, and trees where the stems are strong enough to stand erect and where no other external influence such, for example, as light, is stronger than the influence of gravity. It may be experimentally illustrated by placing a potted plant on its side in the dark and observing the upward curvature of the growing tip after a few hours or at most a few days. Stems thus show negative response to gravity, but most roots show a positive response and grow downward unless their direction of growth is modified by some other influence, such as differences in water content of different portions of the soil or by differences in temperature.

Curvatures of organs due to differences in light intensity are called phototropic movements and the phenomenon is called phototropism, while the phenomenon of response to differences in temperature is called thermotropism. The growing tips of the stems of many common plants are positively phototropic and thus grow toward the stronger light. Many roots are positively hydrotropic; in fact, the phenomenon of hydrotropism is common in the roots of ordinary plants. Roots of trees are commonly found to have grown 20 feet or more toward a source of moisture in the soil and often produce dense growth in wells or sewer pipes where openings allow their entrance. Hydrotropism in roots is readily illustrated by setting into the soil a flower pot (the hole in the bottom having been plugged), planting soaked seeds in a circle around it and keeping water in the pot. The water moves through the wall of the flower pot and keeps the soil near it moist and if the rest of the soil is comparatively dry the roots turn toward the moist soil. In this case hydrotropism is stronger than geotropism.

Movements Due to Water Content.—Turgor movements are common in plant organs. A simple case of this is the drooping of leaves when the amount of water in their tissue becomes

small due to high transpiration or lack of water in the soil or both. Such leaves again assume their ordinary position when the conditions are such that their cells have their normal water content. Turgor may, of course, be a factor, often the limiting one, in the curvature of any growing organ, and may be the mechanism through which external stimuli produce such curvatures, since if the cells are more turgid on one side of an organ than on the other, growth curvature will tend to be toward the side on which the turgidity is less.

In all cases of growth movements in response to stimuli there must, of course, be perception of the stimulus before response can take place, and if the response is not at the point of reception there must be transmission of the stimulus. The time element is involved in all these since neither perception, transmission nor response is instantaneous.

Many plant organs show movements in response to changes in the water content of the cell walls when the cells are either dead or at least no longer carrying on active metabolism. Such movements are illustrated by the twisting of the two halves of the pods of many legumes, such as the Scotch broom, whose pods twist as they dry and break open and thus scatter the seeds. The teeth of moss capsules also bend inward when moist and outward when dry, and the fruits of the storksbill (*Erodium*) coil and uncoil depending on whether they are moist or dry.

Suggestions for Further Reading.

1. Loeb, J.: The Organism as a Whole, From a Physico-chemical Viewpoint, New York and London, 1916.
2. Loeb, J.: Regeneration from the Physico-chemical Viewpoint, New York, 1924.
3. Osterhout, W. J. V.: The Nature of Life, New York, 1924.
4. The books listed under Chapter IX.

PART III.

THE RELATIONSHIP OF PLANTS FROM THE VIEWPOINT OF FORM AND STRUCTURE.

CHAPTER XI.

THE DIVISIONS OF THE PLANT KINGDOM.

THE plant kingdom is divided into four divisions—Thallophytes, Bryophytes, Pteridophytes, and Spermatophytes. These four are separated on the basis of technical characters, but a general idea of each may be conveyed by stating some of the more general characters that are easily observed and mentioning some familiar plants belonging to each.

THE THALLOPHYTES.

The Thallophytes constitute the lowest division because their plants are, in general, the simplest in form and structure, and their reproduction is carried on by less complex organs than those of the higher divisions. Many of the Thallophytes consist of a single cell (Fig. 74), and those that are multicellular lack true differentiation into root, stem, and leaf. A plant body lacking such differentiation is called a thallus, and this gives the name Thallophytes (thallus plants) to the division. Some of the plants have external differentiation into parts resembling stems and leaves (Fig. 82), but the internal differentiation is slight, and in the very few that show some stem-like tissues approximating those of the higher plants the other stem tissues are lacking. The larger kelps (Fig. 82)

growing in the sea along the shores show such tendencies in form and structure but they are the exception among the Thallophytes and not the rule.

The reproduction of many of the unicellular Thallophytes is by division of the mature individual into two new individuals (Fig. 74), and such a process of reproduction is called fission. Reproduction by spores is also common in this subkingdom. Some of these spores possess whip-like outgrowths by which they move through water, and others are without such processes and float in water or air, being carried by the movements of either medium. In many of the species of this subkingdom reproduction is brought about by the union of two similar bodies to form a cell which then grows, directly or indirectly, into a new plant. In other species there is a union of two dissimilar bodies, one of which (the egg) is the female and the other (the sperm) is the male.

Cells which unite and form a cell which then grows into a new individual are called gametes, and gametes may be alike or unlike. If the gametes are alike their union is called conjugation and the resulting spore is called a zygospore, while if they are unlike their union is called fertilization and the resulting cell is called an oöspore. The cell resulting from the union of two other cells, whether they are alike or unlike, is called a zygote, and this term includes both zygospores and oöspores. When an egg is produced by a Thallophyte it is always formed in a one-celled structure (Fig. 76), and this distinguishes this division from the Bryophytes and Pteriodophytes in which the egg is produced in a many-celled structure (Fig. 106).

The Thallophytes comprise two groups—the algæ (Fig. 75) and the fungi (Fig. 97). The algæ have chlorophyll and are thus able to manufacture sugars, starches and other carbohydrates from carbon dioxide and water, while the fungi do not have chlorophyll and are thus dependent on some outside supply for their carbohydrate food.

Many of the algæ have some color other than green, though they all have chlorophyll and they are somewhat superficially divided into four groups—blue-green, green, brown and red. Most of the algæ of all of these groups grow in water and the

others grow in damp places. In fresh water practically all of the algæ are either green or blue-green, but in sea water all four groups are found.

The fungi comprise, among others, the familiar toadstools, mushrooms, puff-balls, and molds, and also the yeasts and bacteria which are microscopic. Many of them are parasitic on other plants, and many others grow on decaying organic matter. The lack of chlorophyll makes many of them somewhat colorless, but a number of species possess some other pigment and some of them are conspicuous because of their color.

THE BRYOPHYTES.

The Bryophytes are the next division above the Thallophytes. They are all small plants and in many of the species the plant consists merely of a flat thallus (Fig. 104) at most only a few inches in length. Many of them, however, are externally differentiated into stem and leaves, but even these possess no internal differentiation into stem tissues and leaf tissues such as characterize the Pteridophytes and the Spermatophytes. They have no roots, though they commonly have very simple outgrowths called rhizoids through which water is absorbed, as well as by other parts.

All of the Bryophytes have two generations—a sexual one (gametophyte) in which the spores are oöspores produced by the fertilization of an egg by a sperm, and an asexual one (sporophyte) in which the spores are produced without any union of cells. These two generations always alternate, the the oöspore producing the asexual generation and the asexual spore producing the sexual generation. This is known as the alternation of generations and in all Bryophytes it is readily recognized by careful examination, the sexual generation being the more conspicuous one and constituting what we ordinarily recognize as "the plant" in this division. Alternation of generations is found in some Thallophytes but it is not a conspicuous character of the division as a whole. Alternation of generations thus begins in the Thallophytes and is completely established in the Bryophytes. The egg

of the Bryophytes is produced in a many-celled structure and this is the technical distinction from the Thallophytes, in which it is produced in a one-celled structure.

This division comprises the liverworts (Figs. 104 and 108) and the mosses (Fig. 110). Two divisions of the liverworts have a plant body consisting of a flat thallus only and one division has external differentiation into "stem" and "leaves." The liverworts are mostly found in damp places, and a few float on water or even grow under water.

The mosses are familiar plants, abundant as to both species and individuals in many places. They are small plants with leafy stems and are most common in wet places, though a good many species grow in dry habitats. At least one species grows submerged in water.

THE PTERIDOPHYTES.

The Pteridophytes are mostly larger plants than the Bryophytes and a few of them reach tree size, though some of them are almost as small as some of the mosses. All of them have roots, stems, and leaves and these show internal differentiation approximating in complexity that of the seed plants (Spermatophytes). They have vascular bundles which function in the movement of water and dissolved substances through the organs of the plant. They lack seeds, and this character distinguishes them from the Spermatophytes above them, while the possession of vascular tissue distinguishes them from the Bryophytes below them.

All of them have alternation of generations and both generations are usually rather readily seen, though the asexual generation is the conspicuous one and the sexual one often escapes notice. The asexual generation is always the one meant when we speak of "the plant" of the Pteridophytes and this is in contrast with the situation in the Bryophytes where "the plant" always refers to the sexual generation.

The division Pteridophytes includes the common ferns (Fig. 113), the scouring rushes, or horsetails (Fig. 124), the club mosses, and the water ferms.

THE SPERMATOPHYTES.

The Spermatophytes are characterized by the production of seeds, and this distinguishes them from the Pteridophytes. They are very numerous both as to species and individuals and most of the plants with which we are familiar belong to this division. Crop plants, weeds, flowering plants, and trees are common representatives. They all have leaves, stems, and roots and these show a high degree of internal differentiation, though in some species one or more of these organs is so reduced as to be inconspicuous. All Spermatophytes have alternation of generations and "the plant" is the asexual generation, the sexual one being reduced to microscopic size.

They are sometimes spoken of as the flowering plants, but since they include the coniferous trees, the grasses, and the sedges as well as the plants that bear ordinary flowers, it is difficult to define the term flower in such a way as to include all of them under this term, and the term seed plants is more satisfactory since all of them produce seeds.

There are two groups of Spermatophytes—the Gymnosperms, which have naked seeds, and the Angiosperms, in which the seeds are produced within an ovary wall. The growth of the stems and roots is always from a group of cells called a meristem (see p. 38) and in this the Spermatophytes differ from the Bryophytes and the Pteridophytes which (with the exception of a few Pteridophytes) grow from single apical cells, one at the tip of each branch.

CHAPTER XII.

SOME ORGANISMS WITH BOTH PLANT AND ANIMAL CHARACTERS.

THE boundary line between the plant kingdom and the animal kingdom is indefinite and there are many organisms that cannot be definitely assigned to either. Three common groups of such organisms are the Myxomycetes (slime molds), the Flagellates, and the Dinoflagellates.

THE SLIME MOLDS.

There are numerous species of Myxomycetes and they are common in many parts of the world. The Myxomycetes are commonly known as slime molds and are abundant on decaying matter in damp places where the light is subdued. They are usually found in forests on old logs and fallen leaves and sometimes on soil where it is rich in organic matter. They have two conspicuous stages—the plasmodium stage (Fig. 70) and the fruiting stage (Fig. 71). The first stage consists of a naked mass of protoplasm often grayish or yellowish in color which grows rapidly over decaying logs or other objects. The plasmodium contains many nuclei but has no cell walls and no separating cell membranes. It is sensitive to light and tends to creep into dark places. It is capable of becoming somewhat hardened and of thus passing into a resting state under conditions unfavorable to its growth.

This plasmodium has no chlorophyll and is thus incapable of making its own food. It often engulfs solid particles of food instead of taking it in the form of solution as is most commonly done by saprophytic plants, and this habit together with the entire absence of cell walls is among the characters which make this stage distinctly animal-like.

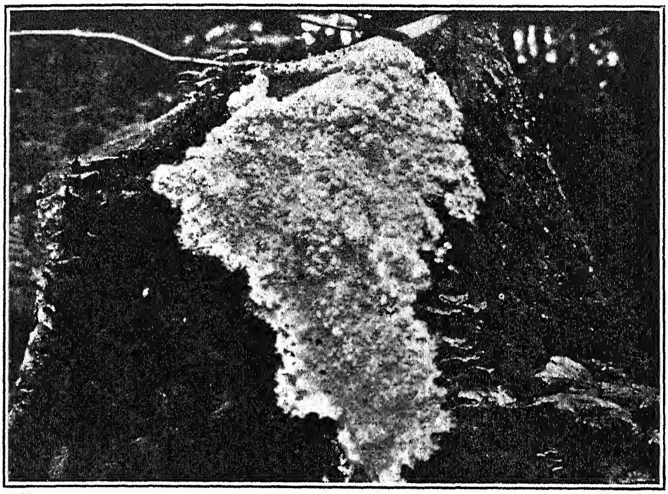

FIG. 70.—The plasmodium of a slime mold (*Brefeldia maxima*) growing on a stump. About one-sixth natural size. This plasmodium was spreading at the rate of 2 cm. per hour. (From Macbride's North American Slime Moulds. Copyrighted, 1922, The Macmillan Company. Reprinted by permission. Photo print by Mr. W. A. Seaman and Mr. John T, Reeder.)

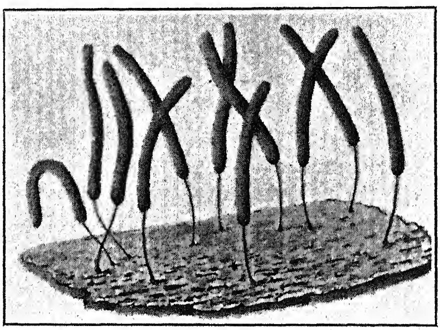

FIG. 71.—A slime mold (*Stemonitis pallida*) in the fruiting stage. (From Macbride's North American Slime Moulds.) Copyrighted 1922, The Macmillan Company. Reprinted by permission.)

When the plasmodium produces the fruiting stage its activity ceases and nothing is left of it but a mass of tough, fiber-like threads. The fruiting stage commonly consists of erect stalks each of which bears at its top a spore case (sporangium) producing numerous spores with cellulose walls, and this stage is thus distinctly plant-like. The spore, under conditions favorable for its growth, produces another plasmodium. The stages by which this takes place differ in the various species, but in many of them the protoplast, when it escapes from the cell wall, moves about actively by means of a single flagellum. This flagellum later disappears and the protoplast becomes somewhat amœba-like. It may then multiply by division (fission) and the cells thus formed coalesce into a plasmodium which is the result of the fusion of several myxamœba—(organisms formed from a single spore).

THE FLAGELLATES.

The Flagellates (Fig. 72) are one-celled organisms living in water and having the power of locomotion by means of one or more whip-like processes called flagella. One species, *Euglena gracilis,* often forms extensive scums on stagnant water and may even produce a dense growth in the water. The cells are green in color, have a nucleus, a contractile vacuole, and a red spot which is sensitive to light but they have no cell wall. In their active state they are elongated and move about by means of a flagellum at one end. In their inactive state they lose the flagellum, become rounded in form, and may remain dormant for some time. Reproduction in *Euglena* may take place either by direct longitudinal division (fission) of the active cells or by the formation of several daughter cells by the resting cells.

Other Flagellates differ somewhat from *Euglena.* Some of them are colorless and some are yellowish or yellow-brown. Some of them, especially the colorless ones, may assume an amœba-like form in which they ingest solid food particles. In some species the cells form considerable mucilaginous matter and are thus held together in colonies. Reproduc-

tion by the union of cells is probably entirely lacking in the Flagellates. It has been reported in a few cases but the reports lack confirmation.

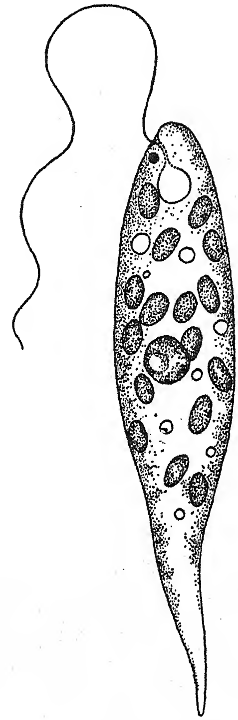

FIG. 72.—*Euglena* (a flagellate), showing nucleus, chloroplasts, eye spot, and flagellum. (Drawn by E. C. Angst.)

The Flagellates are related to the one-celled Thallophytes among plants and to the Protozoans among animals, and there is some reason for regarding them as the starting-point of both of these groups. Among the plant-like characters are the presence of chlorophyll in many of the species and the production of daughter cells by the division of a resting cell. Among the animal-like characters, are the pulsating

vacuole, the amœboid activities of many species, reproduction by longitudinal splitting of the cells, and the entire absence of a cell wall in practically all species. Locomotion by means of long whip-like processes (flagella) or of shorter processes (cilia) is common in one-celled animals and in a number of groups classed as plants.

THE DINOFLAGELLATES.

The Dinoflagellates are unicellular organisms mainly of the sea, but found also in fresh water. Most of them have a cellulose wall composed of a number of polygonal plates sculptured so that they show attractive patterns. A few, however, have naked cells and others have uniformly thickened cellulose walls. The Dinoflagellates move freely through the water by means of two flagella. Some have no chlorophyll and some of them assume an amœboid form in which they ingest small algæ and use them for food. No sexual reproduction (union of cells) has been found in the Dinoflagellates. The most common form of reproduction is by division of the active cells, though resting cells which finally produce several motile daughter cells are also found.

Economically the Dinoflagellates are very important since they form a considerable portion of the plankton of the sea. Plankton consists of small organisms, both plant and animal, mainly microscopic, found in both fresh and salt water. Such organisms serve as food for larger organisms and are thus an important element in the food cycle of fish and other aquatic animals that are used for human food. Plankton organisms are readily collected by towing a net made of bolting silk through the water, and Dinoflagellates have thus been collected and studied in many parts of the world.

Suggestions for Further Reading.

1. Macbride, T. H.: North American Slime Moulds, new and revised edition, New York, 1922.

CHAPTER XIII.

THE ALGÆ.

The Algæ are divided into four groups—blue-green (Cyanophyceæ), green (Chlorophyceæ), brown (Phæophyceæ), and red (Rhodophyceæ). All of these possess the green pigment chlorophyll (see p. 144). The first group, however, have a blue pigment which partially masks the green color, and the third group have a red pigment which rather completely masks it. The color of the brown algæ is due to the fact that the yellow pigments (carotin and xanthophyll) which accompany chlorophyll in all plants are relatively more abundant. In many land plants the amount of chlorophyll is from three to five times as much as that of the yellow pigments, while in the brown algæ the pigments of the two colors are present in approximately equal amounts.

THE BLUE-GREEN ALGÆ (CYANOPHYCEÆ).

The blue-green algæ (Fig. 73) are characterized, in addition to their color, by the absence of sexual reproduction and by the very simple organization of their cells. These are characterized by the lack of a clearly defined nucleus and the lack of definite chloroplasts. The nuclear substance tends to be rather diffuse and is not bounded by a nuclear membrane as it is in the other groups of algæ and in the plants belonging to the other three divisions, and the chlorophyll is diffused throughout the cytoplasm instead of being in definite chloroplasts as it is in the other groups of algæ and in the higher plants. In the simplest blue-green algæ the plant body consists of a single cell, though the cells are often held together in groups by gelatinous material. In others the plant body is a chain or a filament of cells often covered with a sheath of gelatinous matter. Some of these

have resting cells and a few have specialized cells at which the chains break, but the differentiation of cells in this group is extremely slight, and the functions are, in the main, performed by the cells as individuals rather than by the chains, filaments, or colonies as groups. The reproduction is by fission in the one-celled forms. In the more complex forms this is followed by the breaking up of the filaments or chains.

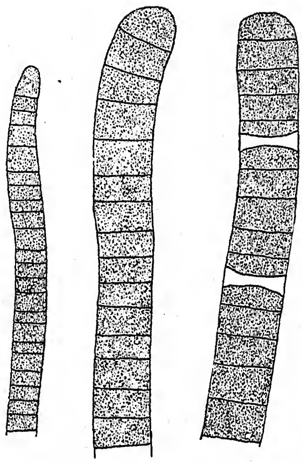

FIG. 73.—*Oscillatoria.* Filaments showing stages in development. Left, a young filament. Middle, a mature one. Right, an old one, breaking at two points. The cells show chlorophyll distributed (not in chloroplasts) and the absence of a definite nucleus. (Drawn by M. W. Phifer.)

The blue-green algæ (Cyanophyceæ) are closely related to the bacteria (Schizomycetes) and these two groups are often placed together under the heading Schizophytes. Their relationship is more fully discussed under bacteria (p. 210).

The blue-green algæ are found in both fresh and salt water and also on soil, and on stones or other objects in damp places. Some of them are found within the bodies of other plants (*e. g.*, the thallus of the liverwort *Anthoceros*) and others on the surface of other plants (*e. g.*, the rockweed, *Fucus*). Some of them combine with fungi in the formation

of lichens. In the first of these relations they are endophytic, in the second they are epiphytic (see p. 369) and in all three they are symbiotic (see p. 364). Some of them endure high temperatures and are common in hot springs. One of them found on the surface of the Red Sea is red in color and this illustrates the fact that morphological characters rather than color determine the real basis of the division of the algæ into the four groups.

The cells of *Glœocapsa* are round and show a distinct cell wall with a gelatinous layer over it. When new cells are formed by the division of mature ones they are held together by this gelatinous matter, thus forming masses, or colonies. Each protoplast shows an outer layer of cytoplasm with the characteristic blue-green color, and a central nuclear portion containing no pigment. The cell division does not involve the formation of chromosomes (see p. 26) in the nucleus, but does involve the formation of definite chromatin granules.

Anabæna forms a bluish-green scum on the surface of quiet water and its decay often causes an offensive odor. Its cells are rounded and are joined together in chains in which occur slightly larger cells called heterocysts at which places the chains tend to break as they become long. All of the cells except the heterocysts continue to have the power of division.

Nostoc forms spherical colonies sometimes as much as ½ inch in diameter, though usually smaller, consisting of gelatinous matter in which are embedded chains similar to those of *Anabæna*. Some of the larger colonies are perfectly spherical and have the appearance of dark-colored grapes, while the smaller ones may be paler in color and somewhat irregular in shape. It is common in ditches and other places where the water is shallow and is also found on damp soil and rocks. When conditions are unfavorable for growth certain cells enlarge, store food, and become resting cells, resuming growth when conditions are again favorable.

Oscillatoria (Fig. 73) has short cylindrical cells joined together in filaments, the whole filament being invested with a covering of gelatinous material. It forms bluish-green masses in water and also in very wet places especially

where water is dripping. The cells of the filament are all alike, there being no heterocysts, and each cell has the power of division. Under the microscope the filaments are seen to have a back and forth movement, and this oscillation has given the name to the genus. *Lyngbya* is similar to *Oscillatoria,* but occurs in salt or brackish water and has larger filaments with a thicker gelatinous sheath.

Lines of Development.—Though the blue-green algæ are not commonly regarded as being important in the evolutionary development of the groups above them, the simplicity of their cells suggests that they may represent an early stage in the development of cells. The great variety of nuclear conditions found during cell division is suggestive of progressive changes in the colloidal system constituting the cell.

THE GREEN ALGÆ (CHLOROPHYCEÆ).

The green algæ are distinguished from the blue-greens by the presence of a definite nucleus surrounded by a membrane, by the presence of chloroplasts, and by the absence of the blue color. The plant body may be a single cell, a filament (either branched or unbranched), a colony of cells, or a thallus. The thallus may be a leaf-like structure one or two cells in thickness, a tube whose walls are one cell thick, a disk several cells thick, or it may be composed of loosely interwoven filaments forming a denser cortex at the surface. Some of the one-celled species have cilia and thus have the power of locomotion in water and some of the colonies are composed of ciliated cells and the whole colony may swim. Many of the green algæ, however, have no cilia and do not have the power of locomotion. Some of them float in or on water, some are attached to solid objects, and still others form growths on solid objects without having definite attachment. They occur in both fresh and salt water. The marine species occur mostly between high and low tide or a little below low tide. Vegetative reproduction occurs by fission. Asexual reproduction occurs by the formation of zoöspores, and sexual reproduction by the union of similar cells (conjugation) or by the union of unlike cells called sperm

and egg (fertilization). The cells that unite, whether like or unlike, are called gametes, and the cell formed by their union is in either case called a zygote.

Chlamydomonas.—In Chlamydomonas the individual consists of a single cell showing a nucleus, vacuoles, a chloroplast, and an eye spot. Locomotion takes place by means of two cilia situated at the end of the cell, which is somewhat oval in shape. The cilia sometimes disappear and the cells thus lose the power of locomotion. Some of the species have a red pigment and one of these species (*Protococcus nivalis*) gives the color to the "red snow" found on high mountains, though the redness of snow is sometimes caused by other algæ.

The reproduction is by spores, and those are either asexual (formed without the union of cells) or sexual (formed by the union of cells). In the asexual reproduction several spores are formed within the mother cells and are set free by the rupture of the cell membrane. These spores are motile by means of cilia and are called swarm spores, or zoöspores. They grow directly into new individuals of the species. Other mother cells, when they divide internally, form ciliated cells which escape and unite in pairs, forming a zygospore. This zygospore is a thick-walled cell, usually formed at the beginning of unfavorable conditions and remaining dormant until conditions are again favorable. During the continuance of favorable conditions reproduction is mainly by zoöspores.

Volvox.—In *volvox* the cells have two cilia and are united so that a large number of them form a hollow spherical colony which has the power of locomotion. A few of the cells of this colony become larger than the ordinary ones and divide forming new colonies. Volvox also has sexual reproduction by means of eggs and sperms produced in certain cells of the colony. Fertilization occurs in the cavity within the colony, and the resulting oöspore when it germinates produces zoöspores which cohere and form a new colony.

Pleurococcus.—*Pleurococcus* forms green mealy growths on trees, rocks, boards, flower pots, and other objects in damp places. In the northern hemisphere it grows more on

the north side of these objects than on the south side if they are in the open, though where they are in the woods or other shaded places it grows on all sides. Dry conditions inhibit its growth, and direct sunlight may also be a factor. Each cell (Fig. 74) is an individual plant, though several of them may stick together for some time after division. All of the functions, both vegetative and reproductive are performed by the single cell. The cell has a definite wall, a nucleus, and a single large chloroplast which is somewhat lobed. The reproduction is by fission only. In unicellular organisms reproducing by fission only, the mature cell divides producing two new cells, and there is in a sense, no such thing as parent and offspring.

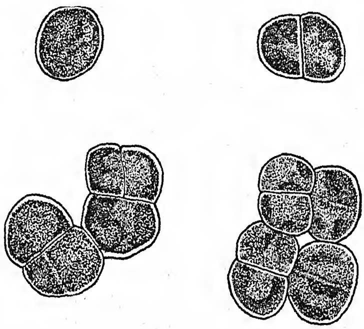

FIG. 74.—*Pleurococcus*. Upper left, a single cell. Upper right, two cells recently formed by the division of one. Below, various stages in cell division. (Drawn by M. W. Phifer.)

Spirogyra.—*Spirogyra* (Fig. 75) is a fresh water alga in which the plant body consists of an unbranched, unattached filament. It forms slimy masses in shallow quiet water, and when these masses are lifted with the fingers or with a stick the filamentous character is very evident. The filament is composed of cylindrical cells set end to end. Each cell has one or more spiral chloroplasts, the edges of which are somewhat irregular. In each chloroplast are embedded several denser bodies called pyrenoids. The cytoplasm forms a thin layer just inside of the cell wall and

within this is the vacuole containing the cell sap, a watery solution which makes up by far the larger volume of the cell. The large amount of water in these cells may be shown by placing them in a salt solution under the microscope. The salt solution draws the water out and the protoplast shrinks up occupying only a portion of the space within the

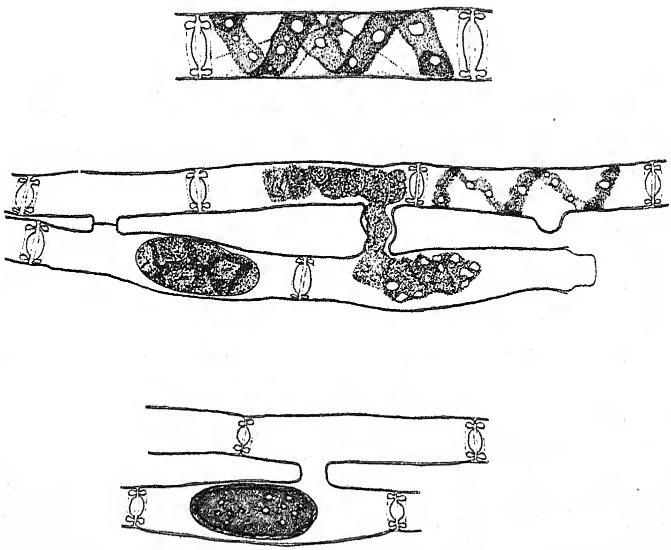

FIG. 75.—*Spirogyra.* Top, a single cell, showing nucleus, cytoplasm, and chloroplast. A layer of cytoplasm lies next to the cell wall and the nucleus is connected with this by strands of cytoplasm. The large spiral body is the chloroplast. The characteristic folds of the wall at the ends of the cell are shown. Middle, stages in conjugation. Bottom, a zygospore and the two cells from which it was formed by conjugation. (Drawn by M. W. Phifer.)

cell wall. The nucleus is situated within the vacuole and is connected with the outer layer of cytoplasm by threads of cytoplasm extending to the outer layer.

There is no differentiation of cells in the filament. All of the cells are alike and all of them perform all of the vegetative functions such as food manufacture, respiration, and the

intake of water. All of these cells are also capable of division and in this way the filament grows indefinitely in length. Long filaments may break in two and new filaments are thus formed by cell division followed by fragmentation.

Reproduction takes place also by conjugation (Fig. 75). In the commoner species this takes place between cells of different filaments. Two filaments lying side by side put out a short tube-like process from the side of each cell, and by the union of the ends of two of these processes, each from a separate filament, the cells are joined together, giving the two filaments a somewhat ladder-like appearance. The wall of the end of each process where they are joined is digested and an open passage is thus established between the two cells. The contents of the two cells now unite forming a thick-walled oval-shaped zygospore in one of them and leaving the wall of the other cell empty. Usually the zygospores are all formed in the same filament. After a time the walls break, the zygospores are set free, and after a period of rest begin growth and form new filaments.

The Desmids.—The desmids are unicellular green algæ of remarkable symmetry and elegance, common in fresh water and occasionally found in brackish water. They are common on the bottom of pools and on submerged plants, and are often found in the plankton of lakes. They are abundant on *Sphagnum* moss and in the pools of *Sphagnum* bogs. There are numerous species and the forms of the individuals are various, such as rounded, crescent-shaped or star-shaped. Each individual is composed of two similar parts and there is usually a median constriction called the isthmus. Each of the halves contains a large chloroplast and the nucleus lies between these. The cell wall is composed of cellulose. It is composed of two halves and its surface is in many species covered with protuberances. In one of the common crescent-shaped species there is a vacuole near each end of the cell in which the rapid movement of small particles of gypsum is readily seen under the microscope. Some species of desmids form filaments of very striking appearance.

Reproduction is by fission and also by conjugation. In fission, the division of the nucleus is followed by the formation

of a wall across the cell between the two chloroplasts. Each of the cells thus formed has one of the halves of the old cell, and by growth at the end next to the new cross wall, it forms a new half like the old one. In conjugation the protoplasts of two cells escape from their walls and unite forming a zygospore, which by nuclear division produces two new desmids.

Ulothrix.—*Ulothrix* is common in fresh water, forming dense growths on rocks, wooden floats or other objects. The plant body consists of an unbranched filament attached by a basal cell which is somewhat different from the others. Each cell has a single chloroplast. All of the cells except the basal one have the power of division and of thus contributing to the elongation of the filament. The asexual reproduction is by means of zoöspores having four cilia and an eye spot. These zoöspores may be formed in any cell of the filament, and a cell may produce one or more of them. They grow directly into new filaments. The sexual reproduction is by means of similar gametes, which may also be produced in cells in any portion of the filament. Both the zoöspores and the gametes are produced by the division of the protoplast within the cell wall, and this is called internal division to distinguish it from the division of a cell into two new ones, each having a portion of the wall of the old cell. The gametes have two cilia and when they fuse the resulting zygospore at first has four cilia, though it soon loses them and becomes a resting spore. When it germinates it does not produce a new filament directly, but produces several zoöspores each of which grows into a new filament. Some of the cells which look like gametes have been found to grow into new filaments and thus function as zoöspores.

Some Marine Algæ.—*Ulva* is a marine alga having a thin, flat, attached thallus somewhat leaf-like in form though lacking the cellular differentiation of the leaves of higher plants. Each cell contains a single chloroplast. The cells produce numerous ciliated zoöspores and gametes and reproduction is similar to that of *Ulothrix* except that the zygospore produces a new thallus directly. *Ulva* is commonly called sea lettuce and is used for food in some countries.

Enteromorpha is a marine alga whose thallus is at first two cells in thickness, but later forms a continuous cavity within by the separation of the two layers. The mature thallus may be round in cross-section and thus make its tube-like structure rather evident or it may be flattened and thus appear ribbon-like.

Codium (Fig. 77) is a marine alga in which the plant body is composed of continuous interwoven filaments giving the plant body a spongy character. The swollen ends of these filaments or of their branches form a cortex at the surface of the thallus. The plant is attached to rocks by a holdfast which is composed of filaments continuous with those of the rest of the thallus. A species common on the Pacific coast of North America occurs in rough water at about the low-tide level and has a branched cylindrical thallus sometimes reaching a length of 1 foot and a diameter of $\frac{1}{2}$ inch. Other species differing considerably in form are found in various parts of the world. The reproduction is by biciliate gametes which in most of the species differ in size, the larger ones being sometimes regarded as female and the smaller ones as male. The union of these produces a spore which is to be regarded as an oöspore if the gametes are unlike or as a zygospore if they are alike. This germinates immediately, producing a new plant. The larger ciliated cells usually functioning as gametes sometimes germinate and produce new plants without union, and thus function as zoöspores.

Vaucheria.—*Vaucheria* occurs in felt-like masses of filaments in fresh water pools and lake margins and on damp ground. Its felt-like character is quite evident to the touch and distinguishes it clearly from slimy algæ such as *Spirogyra*. The plant body is a branched filament (Fig. 76) having many nuclei, but no cross walls. If we take the cell wall as a basis we say the filament is one-celled, but if we take the nucleus as a basis we say that it is many celled. We call such a filament a cœnocyte, and plants having this structure are said to be cœnocytic. The young plants show an attachment to the substratum consisting of a rather colorless portion having branches called rhizoids. A rhizoid is an outgrowth having somewhat the appearance of a root of a higher

plant and resembling it in functioning in anchorage and sometimes in the intake of water, but lacking the cellular differentiation found in roots. The rhizoids may escape

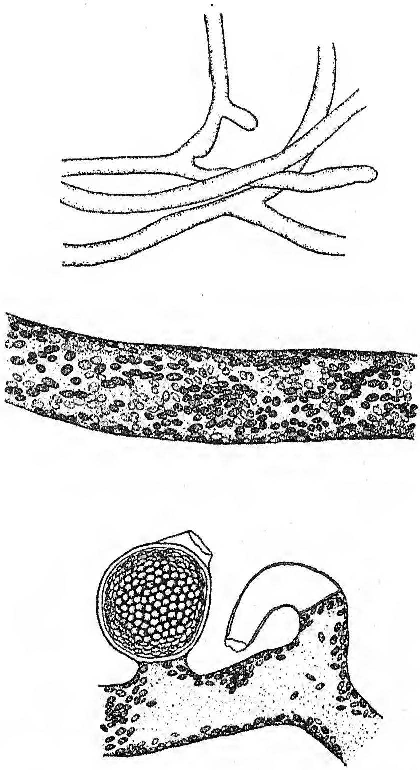

FIG. 76.—*Vaucheria.* Top, filaments, showing branching and the absence of cross walls. Middle, a portion of a filament on a larger scale, showing numerous chloroplasts. Bottom, a portion of a filament, showing an oögonium (left) and an antheridium. (Drawn by M. W. Phifer.)

notice in mounting portions of the mature plants for examination under the microscope. The asexual reproduction of *Vaucheria* is by means of complex zoöspores, so large that they may be seen with the unaided eye. The zoöspore is

formed in an enlargement at the tip of the filament cut off by a cross wall. It contains many nuclei and has numerous cilia, which appear in pairs, one pair opposite each nucleus. Morphologically this zoöspore thus corresponds to a mass of zoöspores such as those produced in *Ulothrix*. When it germinates it produces a new filament.

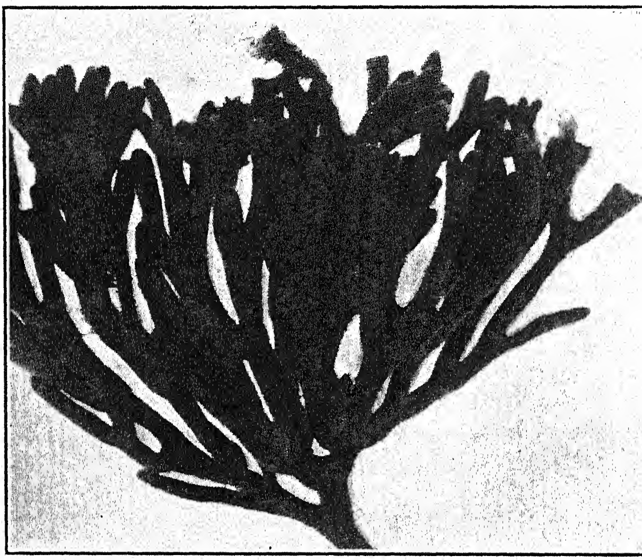

FIG. 77.—*Codium* (a green alga). About one-half natural size. (From U. S. Senate Document 190.)

The sexual reproduction of *Vaucheria* is by the fertilization of an egg by a sperm. The egg is produced in a rounded one-celled structure (Fig. 76) called an oögonium which forms on the side of the filament and is separated from it by a wall but remains attached to it. The sperms are ciliated and numerous and are produced in a slender curved body called an antheridium (Fig. 76) produced near the oögonium. The antheridium is separated by a wall, but like the oögonium remains attached to the filament. The sperms are discharged by the rupture of the wall and move to the oögonium where

one of them enters through an opening and fertilizes the egg, producing the oöspore. In *Vaucheria* the oöspore has a heavy wall and is rather more resistant to unfavorable conditions than the vegetative phase of the plant. When it germinates it produces a new filament directly. One of the ways in which *Vaucheria* differs from the green algæ previously described is in having gametes that are unlike, thus showing distinctly male and female characters.

Some interesting experiments have been made on *Vaucheria* and it has been found that it responds readily to variations in light intensity and in the nature of the solution in which it is grown. The continuation of the three phases—vegetative growth, zoöspore production, and gamete production—may be thus varied and some other changes may be made in the nature of the reproduction. When the conditions which we call normal are restored the plant returns to its usual life history. Others of the lower plants have been found to be somewhat plastic and capable of showing modifications of the individuals as a result of changes in environment.

Coleochæte.—*Coleochæte* is a fresh-water alga, the plant body of which is a flat thallus visible with the unaided eye, occurring on the stems and leaves of water plants. One common species has a disk-like thallus several cells thick, composed of radiating rows of cells. The asexual reproduction is by means of biciliate zoöspores which may be produced in any cell of the thallus. Each of these may grow directly into a new thallus. The sexual reproduction is by the fertilization of an egg by a sperm. The antheridium is a simple structure produced in the thallus by the division of a cell into four cells each of which produces a sperm with two cilia. The oögonia are also produced in the thallus usually near its margin. When fertilization takes place the resulting oöspore is thick-walled and, on germination, produces a body consisting of several cells each of which produces a zoöspore that escapes into the water and produces a new thallus. This body is sometimes thought of as a separate generation and since in the sexual reproduction of *Coleochæte* it alternates with the thallus, the life history of this plant is regarded as consisting of an alternation of generations, the sexual genera-

tion (thallus) alternating with the asexual generation (the zoöspore-producing body formed by the germination of the oöspore). This view is strengthened by the fact that in another species of *Coleochœte* whose thallus is a flat mass of fibers the fibers grow around the oöspore forming a sort of case and the resting stage of the plant is thus a several-celled body with an oöspore within it. If we define alternation of generations as the alternate occurrence of an asexual generation and a sexual generation in the life history of a plant then this plant has alternation of generations. If on the other hand we take the view that the number of chromosomes (see p. 27) in the nucleus of each cell of the asexual generation is double that in the nuclei of the sexual generation, then this plant apparently does not have alternation of generations. The latter is the situation in the Bryophytes, Pteridophytes and Spermatophytes where the alternation of generations is universal, and it is described more fully under Bryophytes (p. 239).

The Stoneworts.—*Chara* is a much-branched plant sometimes almost a foot in length occurring in fresh water. It may form dense growths or it may occur as individual plants and may come practically to the surface or be at a little greater depth. It is attached to the substratum by rhizoids. Some of the species are encrusted with calcium carbonate being thus hard to the touch, and this fact has given the name stonewort to the family of plants to which they belong.

The plant consists of nodes, at which there are numerous whorled branches, and elongated internodes between these. These branches are limited in their elongation and thus have a definite and fairly regular length, but at some of the nodes other branches also occur which have indefinite growth and thus become much elongated. The elongation of the main axis and of these long branches is by the continued transverse division of an apical cell. Each cell thus cut off is again divided by a transverse wall and the lower one elongates forming the one-celled internode often several centimeters in length, while the upper one continues to divide and forms a disk of cells at the node and also forms the lateral branches and in the base of the plant forms the rhizoids.

The vegetative reproduction takes place by means of special tuber-like bodies. There is no asexual reproduction but the sexual reproduction is rather complicated. The oögonia and the antheridia are both large enough to be seen with the unaided eye, and the latter are conspicuous because of their orange color. They are both borne at the nodes and are usually close together. The oögonium begins its development as a single cell, but is later surrounded by five spirally arranged cells forming a projecting crown at the summit, and a single cell is also cut off at the base by division of the original cell. The antheridia arise by the division of a mother cell into eight cells from which is finally produced a complicated hollow globular structure producing numerous spiral sperms, each having two cilia. When the oöspore germinates it produces a segmented filament with rhizoids, and the plant body is formed by a lateral growth from this filament.

Nitella is another genus of stoneworts occurring commonly in lakes and ponds and having much in common with *Chara* in its structure and reproduction. Its long internodal cells furnish excellent material for observing under the microscope the circulation of protoplasm in the cell.

The Diatoms.—The diatoms (Figs. 78 and 79) are unicellular plants occurring in great numbers in both fresh and salt water. They are found in torrid, temperate and Arctic regions and in both still and running water. They are common in lakes, ponds and pools and are also abundant on stones in clear, cold, swift mountain streams and are even found in soil. They are probably more nearly universal in their distribution over the earth than any other group of plants except the bacteria.

The cells are mostly brown in color because of the presence of one or more brown bodies called chromatophores. Chlorophyll is present in these bodies but does not show, probably because of the abundance of the yellow pigments that accompany it. In nearly all of the species the cell wall contains so much silica that it is hard and rigid. This wall is very resistant and endures conditions that would destroy ordinary cellulose or lignin walls, and fossil diatoms are thus very common. It is not destroyed by heat or by the action of

even strong acids. The wall is composed of two parts overlapping somewhat as an ordinary paper box and its cover overlap. The overlapping portion is called the girdle. The wall is sculptured with lines, dots or grooves and many

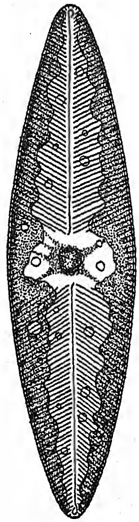

FIG. 78

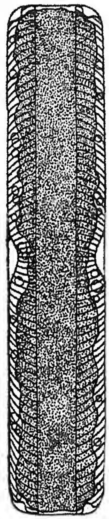

FIG. 79

FIG. 78.—A diatom (*Navicula asper*) valve view. The nucleus is in the center of the cell. The straight line extending lengthwise is the raphe. The diagonal lines radiating from this are markings on the silicious cell wall. The stippled portion at each side represents a chromatophore. The circles represent oil globules. Magnified about 500 diameters. (Drawn by E. C. Angst.)

FIG. 79.—Girdle view of the same diatom shown in Fig. 78. The two straight lines extending lengthwise of the cell mark the borders of the overlapping portion (girdle) of the two halves of the silicious wall. The chromatophore lies under this and projects from it at each side. Six thickened portions (nodules) of the wall are shown (two at each end and two in the middle). Magnified about 500 diameters. (Drawn by E. C. Angst.)

of the species are extremely beautiful when seen under the microscope. This has led to calling the diatoms "the jewels of the plant world."

Diatoms are extremely various in shape. Some species are boat-shaped, some (Fig. 80) are like a circular disk, some

triangular, some are like straight rods, others like curved rods, and the form of others is quite complex. Every diatom has two aspects (Figs. 78 and 79) and its shape may not appear the same when seen in these two aspects. The two halves of the cell are called the valves and the part where they overlap is called the girdle. We may thus see the diatom from the girdle view or the valve view and the two are often quite different in shape and sculpturing. In the case of flat disk-like diatoms the valve view only is likely to be seen, but in some others both views of various individuals

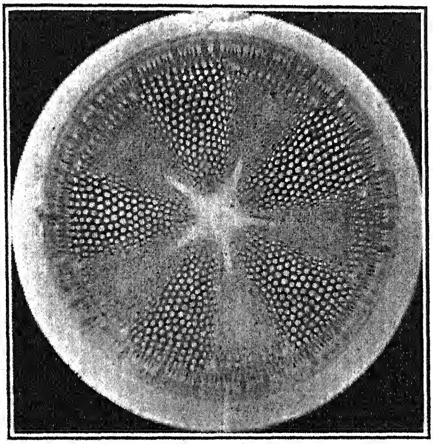

FIG. 80.—"Sun shield" diatom (*Heliopelta*). Magnified about 400 diameters. (Photomicrograph by G. H. Needham.)

of the species may be seen. There is usually a cleft in the valve called the raphe. In many forms there is a rounded nodule at each end of the raphe and in some at its middle also, and the raphe thus gives a rather characteristic appearance to the valve view. The valves are rather thin and in many of the species the chromatophores and sometimes the nucleus can be seen. Much of the reserve food of diatoms is in the form of oil, and the yellow, highly refractive oil droplets are frequently seen. Small circular cavities, or aëroles, are sometimes present in the substance of the wall

itself and these may appear to be in the protoplast. There are often pores present in the walls through which the gelatinous secretion of the protoplast is extruded.

There is commonly a gelatinous pellicle over the silicious shell, and in many species the cells are united by this gelatinous matter and thus form colonies. These colonies may be branched or unbranched, and may be attached to plants or other objects in the water or they may be free-floating. In some of the attached forms there is a long gelatinous stalk with a single cell at the end. Some colonies are in the form of zigzag chains whose cells are rectangular and are joined together at the corners.

The reproduction is of two kinds—fission and conjugation. In fission the protoplast divides, the two halves of the wall separate, and each of the new cells then forms a new half wall whose edge fits within the edge of the old half. This, of course, results in constantly decreasing the size of the cells, and eventually a cell called an auxospore is formed by a protoplast which frees itself entirely from the old silicious wall, and then forms an entirely new wall. By this means the size of the cell is increased.

Conjugation takes place by the union of two nuclei, which may be from the same diatom, or from two separate diatoms, and is sometimes a rather complex process. In all cases, however, the resulting spore is at first a naked protoplast, called an auxospore and this forms an entirely new wall. This auxospore differs from the one described above in being sexually produced, but both serve to rejuvenate the species.

Many diatoms have the power of locomotion, but this seems to be accomplished by creeping on a solid surface and they are probably not free-swimming organisms. No cilia or projecting processes have been found, and it seems most probable that locomotion is accomplished in some way by means of the gelatinous pellicle.

Diatoms are economically important in several ways. One of them is that they are a large primary source of food for aquatic animals such as fish. Some fish feed directly on diatoms and others feed on small animals which depend

finally on diatoms for food. The food cycle of aquatic animals must in all cases involve somewhere an organism that can synthesize its own food, and this usually is the diatoms or other algæ. Diatoms, in the form of diatomaceous earth, are used for insulating material, especially in heat insulation, and they are also used as a filler in manufacturing explosives.

Lines of Development.—The lines of development seen in the green algæ here described may be grouped under three heads: (1) the cell; (2) the plant body; and, (3) the method of reproduction.

1. All of the green algæ, as stated before have a definite nucleus, surrounded by a membrane, and have the chlorophyll in definite bodies called chloroplasts. In these particulars their cells show a distinct advance over those of the blue-green algæ.

2. The plant body may be a single-cell motile by means of cilia (*Chlamydomonas*); a single-cell motile without cilia (many diatoms); a colony motile by cilia (*Volvox*); a single non-motile cell (*Pleurococcus*); an unbranched filament (*Spirogyra*); a branched filament (*Vaucheria*); a thin thallus (*Ulva*); a tube whose walls are one cell thick (*Enteromorpha*); a thallus several cells thick (*Coleochœte*); or a thallus composed of filaments forming a cortex at its surface (*Codium*). Many of these are distinctly more advanced than any of the blue-green algæ. The plant body in many of the green algæ is attached and this is also a character not found in the blue-green algæ.

If we include *Chara* and *Nitella* with the green algæ we have a stem-like body with whorled branches, showing localized growing regions and considerable differentiation among its cells such as rhizoids, nodal cells, and internodal cells. It makes little difference in tracing lines of progress whether we place these plants with the green algæ as advanced forms or regard them, as is often done, as a separate group between the green algæ and the Bryophytes.

3. Reproduction may be by fission (*Chlamydomonas, Pleurococcus,* desmids, and diatoms); by several ciliated cells resulting from the internal division of a cell (*Ulothrix, Ulva,* and *Enteromorpha*); by a large, multinucleate, multi-

ciliate zoöspore (*Vaucheria*); by the union of similar vegetative cells to form a zygospore (*Spirogyra*); by the union of similar motile gametes (*Ulothrix*, *Ulva*, and *Enteromorpha*), of large and small motile gametes (*Codium*); or by the fertilization of an egg by a sperm (*Vaucheria* and *Coleochæte*). There is also a sort of alternation of generations in *Coleochæte*, though it must be remembered that this plant has not been definitely shown to qualify as an alternation by the chromosome test.

In many of these characters the green algæ show characters that are suggestive of progress toward the higher plants.

THE BROWN ALGÆ (PHÆOPHYCEÆ).

Nearly all of the brown algæ are marine. The plant body is attached and varies from filaments a few inches in length as seen in *Ectocarpus* and its close relatives to structures 100 feet or more in length and showing considerable differentiation both in external form and internal structure, as seen in the large kelps (Fig. 82). The brown algæ do not form starch, but they do form other complex carbohydrates and some of them contain compounds closely resembling the sugars of the higher plants.

Ectocarpus.—Ectocarpus grows in salt water and is attached to the substratum or to other plants. It consists of multicellular, branched filaments showing either a single row of cells or several parallel rows. Zoöspores which are laterally biciliate and develop directly into new filaments are produced in one-celled sporangia, which may be at the end of a few-celled lateral branch or in the filament itself. The gametes are also biciliate and are produced in many-celled structures called gametangia which, like the zoösporangia, may be either in the filament itself or on short branches. In some cases the gametes are of two sizes and the process of union is said to resemble the fertilization of an egg by a sperm. Some of the ciliated bodies produced in the multilocular gametangia are thought by some to germinate without union thus producing new filaments directly, and for this reason the structure is often called a sporangium instead of a gametangium.

The Kelps.—*Laminaria* (Fig. 81) is a genus of leathery leaf-like kelps found near low tide and at greater depths on both coasts of North America and in other parts of the world. In one common species the plant body is several feet in length

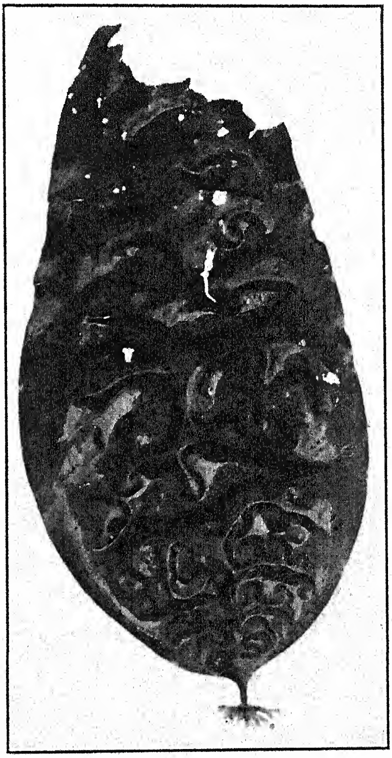

FIG. 81.—A kelp (*Laminaria*), showing blade-like portion (frond) stalk (stipe), and holdfast. Much reduced in size. (From U. S. Senate Document 190.)

and the stipe is short and is attached to stones or other objects by a branched holdfast. The zoöspores are laterally biciliate and are produced in cells at the surface of the blade-like portion of the plant. It shows alternation of generations,

the plant ordinarily seen being the sporophyte. The zoöspores produce small filamentous male and female gametophytes. These produce eggs and sperms, and from the oöspore resulting from fertilization the sporophyte is produced. Some species have a perennial stipe on which a new blade is produced each year from meristematic tissue, the old blade being pushed off by the growth of the new one.

Nereocystis (bladder kelp) (Fig. 82) is a large marine plant found abundantly on the Pacific Coast of North

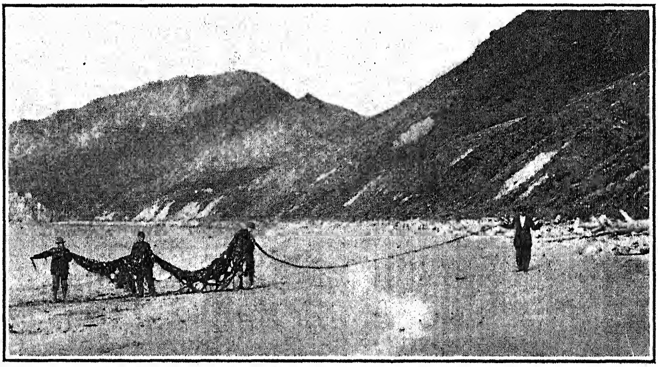

FIG. 82.—A plant of bladder kelp (*Nereocystis*) photographed on a beach on Kodiak Island, Alaska. This kelp grew in a nearby bed in water about 40 feet deep. The holdfast, attached to a rock, lies on the beach at the extreme right. The rope-like portion of the stipe is held by the first man and the bulb and the bases of the fronds by the second. The fronds are held by the other two. (From Report 100, U. S. Department of Agriculture.)

America. It occurs below extreme low tide and is often in water 30 feet or more deep. It has a long rope-like stipe anchored to a rock or other object and enlarging upward into a hollow bulb-like float on which are borne two groups of long ribbon-like fronds. The whole plant is very commonly 40 feet long and sometimes reaches a length of over 100 feet. It thrives in strong tideways, and the hollow portion and the fronds often form a dense covering on the waters which impedes the navigation of small boats. The growing region is the upper portion of the stipe and the

lower portion of the fronds. In the very young plants (Fig. 83) there is only one frond and this splits at the base, thus producing the two groups of fronds as growth continues.

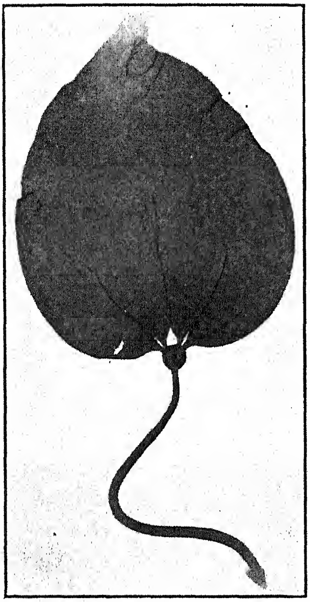

FIG. 83.—A young bladder kelp with one frond showing the basal splitting resulting in the formation of two groups of fronds in the mature plant. (From Report 100, U. S. Department of Agriculture.)

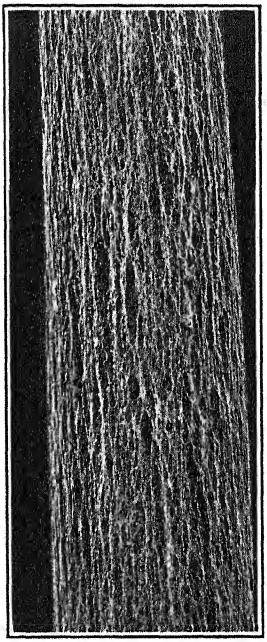

FIG. 84.—Sieve tubes in the hollow portion (pneumatocyst) of bladder kelp. The sieve tubes form a cobweb-like layer on the inner surface of the pneumatocyst, which was split in two. The black band at each side is the cut surface of the pneumatocyst wall. (Photograph by C. M. Child.)

The hollow portion of the stipe has a cobweb-like layer of very small tubes on its inner surface (Fig. 84) which are similar in structure and function to the sieve tubes of higher plants. Laterally biciliate zoöspores are produced in

patches on the fronds, and the plant described is the sporophyte. The gametophytes are of two kinds, male and female, and are similar to those of *Laminaria*. This kelp is apparently annual, the small plants being visible in quiet water at low tide in early spring, and reaching maturity in summer. It is not definitely known, however, how long the sporelings exist before becoming large enough to be visible. During the winter most of the old plants break loose from their anchorage on the rocks and drift away so that by spring the beds have practically disappeared.

Macrocystis is a perennial kelp forming dense beds in the ocean along the California coast and other parts of the Pacific Coast of North America. It has numerous small fronds with a bulbous float at the base of each.

Both of these large kelps and a few others have some economic importance. They contain considerable potash and are an available source of it if the price should be high. Organic acids, acetone, and high-grade charcoal can be made from them. All of these products have at various times been prepared from these kelps on a commercial scale. The kelps also contain much colloidal matter of a gelatinous character, and soap is made from this. They also contain iodine, but the quantity of this is small.

The name kelp is applied to all of the plants belonging to the family Laminariaceæ. There are several other genera besides the three described above. One of the most remarkable of these is *Postelsia*, a plant that flourishes on rocks in heavy surf and has an erect stipe, a foot or more in height with a dense cluster of ribbon-like fronds at the top, the whole plant thus having somewhat the appearance of a small, very flexible palm tree.

Rock Weed.—*Fucus* (Fig. 85) is common on both coasts of North America and in many other parts of the world, occurring mainly between high and low tide. The thallus is a forked leathery body (Fig. 86), usually a foot or less in length, flat above and showing a midrib, but rounded below and attached to stones or other objects by a disk-shaped holdfast. It is commonly called rock weed, or bladder wrack. Some of the species have inflated bladdery portions along

the thallus, and these and the thickened ends of the thallus where the sperms and eggs are borne often break with a popping noise when the plants are stepped on at low tide. It has no asexual reproduction. The sexual reproduction is by the fertilization of eggs by sperms. The eggs are produced in oval-shaped, short-stalked oögonia (Fig. 88), eight to each oögonium, and the sperms are produced in large numbers in small antheridia, borne on slender, branched filaments. Both the oögonia and the antheridia are borne in thickened

FIG. 85.—Dense growth of rockweed (*Fucus*) exposed at low tide on an Alaska beach. (Photograph by S. M. Zeller.)

portions at the ends of the branches of the thallus (Fig. 87). They are on the inner surface of the cavities called conceptacles which open to the surface of the thallus through a slight elevation. Sterile hair-like processes called paraphyses also grow from the inner surface of the conceptacle and some of these project from the opening. Eggs and sperms are commonly discharged into the sea water and fertilization usually takes place outside of the plant. The oöspore germinates, producing a new thallus. In the first division

of the cell by the cross wall the two cells formed are similar in appearance, and one of them functions as a rhizoid cell, eventually by continued divisions producing the holdfast, while the other one produces the distal portions of the thallus. It has been found that it is not necessarily predetermined which of these cells functions as the rhizoid cell, but that this may be governed experimentally either by light intensity or by the direction of an electric current. The growth is localized and results from the continued division of an apical cell. The forking of the thallus results from the more rapid growth of the cells at the sides of this apical cell.

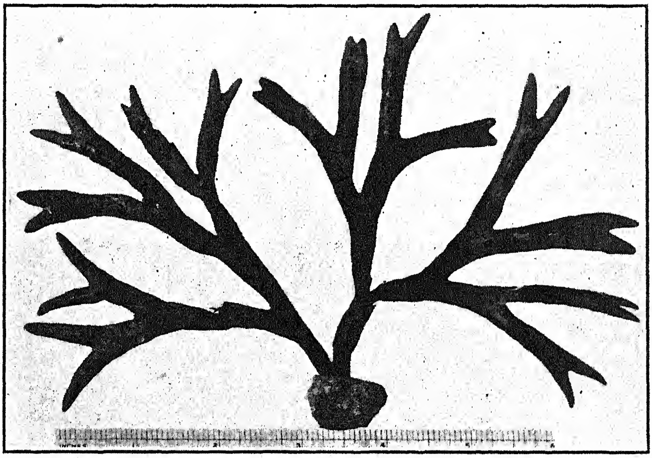

FIG. 86.—A *Fucus* plant growing on a small stone. This plant shows the characteristic forking of the thallus. The oögonia and antheridia are borne in cavities (conceptacles) near the tips of the branches. (Photograph by S. M. Zeller.)

The thallus of *Fucus* is composed of loosely arranged fibers and it also contains much gelatinous matter. The toughness of this thallus enables it to stand the rough treatment that it receives in the beating of waves on the shore. On hot summer days at low tide this thallus is exposed to dry conditions and rather high temperatures, while a few

hours later it is again submerged in sea water and subjected to a much lower temperature. The mucilaginous matter probably assists in resisting drying and also in initiating

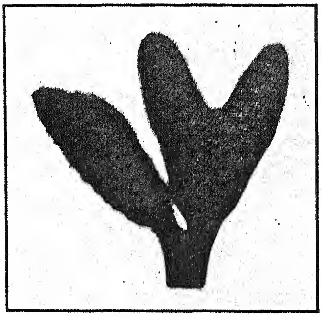

FIG. 87.—Fruiting tips of *Fucus*. Each raised spot marks a conceptacle. (From Report 100, U. S. Department of Agriculture.)

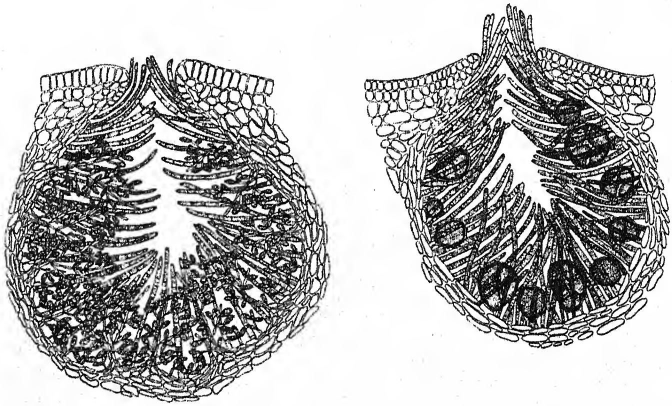

FIG. 88.—Sections of conceptacles of *Fucus*. Left, antheridia and paraphyses. Right, oögonia and paraphyses. Several oögonia show stages in the formation of eggs. (Drawn by M. W. Phifer.)

the extrusion of eggs and sperms from the conceptacles. The thallus has the power of regeneration, new growths being formed where portions of the old thallus have been worn away. The thallus of one species of *Fucus* is used as a medicine.

Lines of Development.—Some of the outstanding characters of the brown algæ are: (1) the development of a rather highly differentiated body, such as that of the large kelps, which has some points in common with the body of the higher plants; (2) the localization of meristematic tissue resulting in the annual production of new parts as in some species of *Laminaria;* and, (3) the laterally biciliate zoöspores and sperms as contrasted with the apically biciliate ones of the green algæ. Definite alternation of generations is also established, the asexual generation (sporophyte) being characterized by the 2X (diploid) number of chromosomes in the nucleus, and the sexual generation (gametophyte) by the X (haploid) number.

THE RED ALGÆ (RHODOPHYCEÆ).

The red algæ are nearly all marine and all of them are attached to the substratum. They occur between high and low tide and also at deeper levels down to 150 feet or more. The green color of the chlorophyll is completely concealed in many of them by a red pigment, but in others the character or amount of this pigment varies, and the plants show a purplish or reddish-brown color. The chromatophores are of various shapes and there are many of them in each cell. The red algæ do not contain true starch, but do contain a reserve food which produces a red color when treated with iodine, instead of the blue color given by the true starch of most plants.

The vegetative body varies from small, delicate, branched filaments to a flat thallus 2 feet or more in length, composed mostly of matted filaments. Many of the delicate filamentous species are very beautiful because of their form and color, and are often collected and pressed on cards for this reason. Some of the larger filamentous species are encrusted with lime and have a coral-like appearance. These usually occur on rocky shores where the surf is strong.

Nemalion.—The thallus of Nemalion is a cord-like, branched structure a few inches long, and thick enough to be seen with the unaided eye. It is composed of delicate longitudinal

filaments held together by gelatinous matter and radiating in a somewhat fan-shaped form at the tips. Each of these filaments is composed of a single row of slightly elongated cells.

The antheridia are produced in clusters at the end of a branch of a filament, and the bodies corresponding to the motile sperms of the sexual green algæ are non-motile and are called spermatia (sing., spermatium). The structure producing the female nucleus is called a procarp. It has an enlarged base and is prolonged upward into a slender process called the trichogyne. The spermatium lodges against the trichogyne, an opening is formed in the wall of each, and the spermatium nucleus passes down to the base of the procarp where it fuses with the female nucleus. The trichogyne then shrivels and the union of the male with the female nucleus is followed by the production of a cluster of short filaments at the end of each of which is produced a spore called a carpospore. The whole structure produced as the result of this fertilization is called a cystocarp. It consists of the central base of the procarp, the filaments and the carpospores. The carpospores are asexual and when they germinate they produce the sexual filaments forming the thallus. It has been thought that in the alternation of generations in this plant the cord-like thallus is the gametophyte and the cystocarp the sporophyte, but some recent work has created doubt about this. According to this work the sporophyte consists of only one cell, and all of the visible parts of the plant are gametophyte.

Polysiphonia and Rhodymenia.—*Polysiphonia* (Fig. 89) consists of clusters of multicellular branched filaments tapering at the tips. As seen under the microscope the filament appears segmented, each segment being composed of a few parallel longitudinal cells all of the same length. When a filament is crushed or a cross-section is made, it is evident that each segment is composed of a central cell with the other cells arranged around it in a single layer.

The plants are all alike in their general vegetative structure, but in their reproductive parts they are of three kinds—male, female, and asexual. The asexual plants produce

spores which are borne in fours and are called tetraspores (Fig. 89). A sporangium is produced on the side of the central cell of an internode, and its contents, by division, produce the four spores within the sporangium wall. These

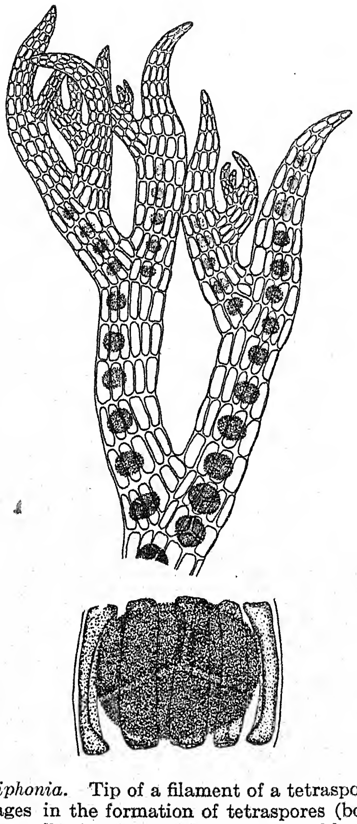

FIG. 89.—*Polysiphonia.* Tip of a filament of a tetrasporic plant, showing branching and stages in the formation of tetraspores (bottom of filament) from spore mother cells (near tips). Below, an older tetrad of spores breaking the filament as they mature. (Drawn by M. W. Phifer.)

tetraspores escape from the filament and produce the male and the female filaments (Fig. 90), which have organs somewhat similar to those of *Nemalion.* The whole antheridium, however, is cast off and functions as a sperm, and the procarp

differs from that of *Nemalion* in including several vegetative cells in addition to the egg-producing portion and the trichogyne. When fertilization occurs a rather complicated growth takes place involving some of the surrounding vegetative cells, and the resulting cystocarp (Fig. 90) is an urn-shaped body with a wall around it within which are borne the club-shaped carpospores. When these carpospores germinate they produce the tetrasporic plants, and the life history is thus complete.

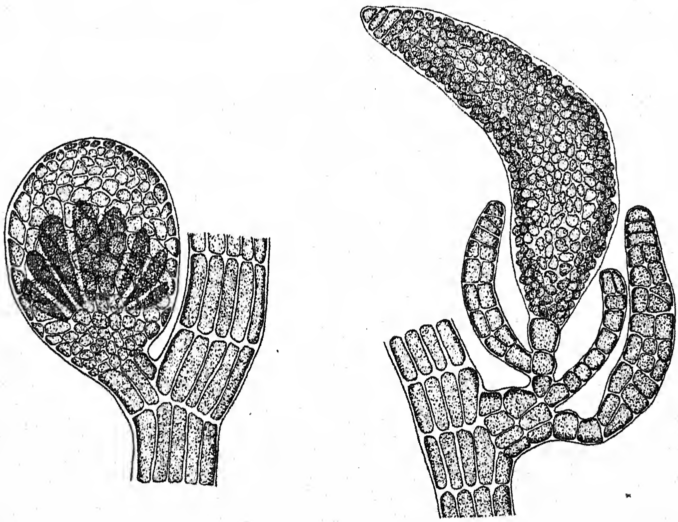

Fig. 90.—*Polysiphonia*. Left, portion of a filament and a cystocarp with carpospores. Right, portion of a filament with an antheridium and three small vegetative branches. (Drawn by M. W. Phifer.)

It is evident that the sporophyte phase here consists of two parts—the cystocarp and the tetrasporic filament—the cystocarp being attached to the female filament. The sporophyte phases have the 2X (diploid) number of chromosomes, and the gametophytes have the X (haploid) number. The number of chromosomes in this case is 40 in the sporophyte and 20 in the gametophyte.

Rhodymenia has a thallus often reaching a length of 2 feet or more and a width of several inches. It is attached to

stones, shells, or other objects and occurs at a depth of several fathoms. It is found in the sea along both coasts of North America and in other parts of the world.

Economic Uses.—Several of the red algæ are made use of by man. Agar agar, which is widely used in preparing solid media for the growth of microörganisms in laboratories, is prepared from *Gracilaria* and other red algæ. A species of *Rhodymenia* constitutes the food called dulse used in some European countries, and a species of *Iridæa* is dried and used as food by the natives in some portions of Alaska. Certain red algæ are also used as food in Japan. Irish moss, or carrageen, is a medicine consisting of the thallus of either *Chondrus crispus* or *Gigartina mamillosa.*

Lines of Development.—One of the striking characters of the red algæ is that, though they grow in water, no motile bodies are concerned in their reproduction, both the male gametes and the tetraspores being without cilia. The fact that the spermatia are non-motile involves their reception by a special outgrowth (the trichogyne) which passes the male cells down to the female nucleus. This may be called indirect fertilization and suggests in a general way the fertilization occurring in flowering plants where the pollen grain is received on a stigma and one or more nuclei are passed down to the embryo sac through a tube, but, of course, differs from it in many particulars. Another striking character of the red algæ is the production of a cystocarp, making the life history rather complicated.

Suggestions for Further Reading.

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7. West, G. S.: A Treatise on the British Freshwater Algæ, new edition, revised by F. E. Fritsch, Cambridge, 1927.

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CHAPTER XIV.

THE FUNGI.

THE fungi are the thallophytes that have no chlorophyll, and are thus incapable of making their own carbohydrate food, and must live as parasites (see page 364) or saprophytes (see page 366). Some of them are unicellular but in many of the groups the plant body is a mycelium composed of threads called hyphæ (sing., hypha). In many of the fungi (*e. g.*, the bread mold) the plant body is composed of a loose mass of these hyphæ, while in others the mycelium is less conspicuous and a definite fruiting body, often quite solid (*e. g.*, the bracket fungus, Fig. 99), is produced and this is the plant that we commonly see.

Many fungi contain pigments and may thus have a conspicuous color such as yellow, red, flesh color, purple or black. Some fungi produce no spores and some produce only one spore in a cell, but many produce numerous spores which are borne in certain definite ways. A spore is a cell modified so as to reproduce the plant, and a spore is thus commonly one-celled, though the reproductive cells adhere in some fungi forming a four-celled structure called a compound spore.

The fungi naturally fall into four groups: (1) the bacteria (Schizomycetes); (2) the thready fungi (Phycomycetes); (3) the sac fungi (Ascomycetes); (4) the basidium fungi (Basidiomycetes). The Ascomycetes and the Basidiomycetes are often grouped together under the name Eumycetes and are called true fungi as distinguished from the Phycomycetes which are then called alga-like fungi. There are a considerable number of fungi whose life history is not sufficiently known to place them definitely in any of the above groups and these are classed for the present as Imperfect Fungi.

THE BACTERIA (SCHIZOMYCETES).

The bacteria are mainly one-celled plants reproducing by fission (Fig. 91), and are the smallest of all known organisms. They are also, as individuals, probably the most numerous of all organisms and are found in the greatest variety of places. They are common in both fresh and salt water, in soil, in air, on living plants, and in and upon the bodies of animals, including man. They resemble the blue-green algæ in the simplicity of their cells and in their reproduction, but differ from them in having no chlorophyll.

FIG. 91.—Bacteria showing chains and colonies. (From Mansfield.) (After Flugge.)

Though there is considerable irregularity in some species, the bacteria are mainly of three shapes—spheres, rods, and spirals. In measuring the size of bacteria, a very small unit is necessary and the micron, which is $\frac{1}{1000}$ of a millimeter, or $\frac{1}{25000}$ of an inch, is used. One of the common spherical bacteria is 0.8 micron in diameter, and a common size for rod-shaped forms is 2 by 0.5 microns. It would take about 12,000 of the latter placed end-to-end to extend around an ordinary lead pencil. While these sizes are representative of many bacteria, some of the spiral species may reach as great a length as 40 microns.

The bacteria have a definite cell wall, usually composed of a nitrogen-containing substance, and in some cases known to be chitin, a substance also found in the cell walls of some

other fungi and in the body walls and wings of grasshoppers and in the body walls of crayfish and other related animals. Many of the bacteria surround their walls with mucilaginous material, and the tubercle bacillus envelops itself in a capsule of fatty matter. Bacteria do not have chlorophyll and in many cases the cultures when grown on agar or other solid media have a muddy-gray appearance. Some of them, however, produce pigments outside of the cells, either in granules or in solution and the colonies may be violet, blue, green, or red. The nucleus is not surrounded by a definite membrane, and the nuclear substance is somewhat diffuse. In this they closely resemble the blue-green algæ.

Some bacteria are non-motile, while others (Fig. 92) possess the power of locomotion by slender outgrowths from the cell, called flagella. There may be only one flagellum, a single group, two groups, or the whole cell may be covered with them.

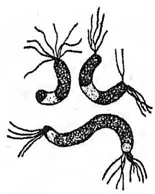

FIG. 92. — Bacteria (*Spirillum*) with flagella. (From Mansfield.) (After Fischer.)

Reproduction is by fission which goes on rapidly. Resting cells which endure unfavorable conditions are often produced and these are commonly called spores. There is only one spore in each cell and it is produced by the rounding-up of the protoplast within the cell wall and is finally set free by the disintegration of the wall.

Though the bacteria as a group are unicellular, some of them, such as the sulphur bacteria (*Beggiatoa*) regularly form filaments, and another group of organisms (the myxobacteria), whose individual cells resemble ordinary bacteria form colonies similar to the plasmodia or even the sporophores of slime molds.

The so-called filterable viruses which produce certain diseases of plants and of man and other animals, are different from ordinary microörganisms. They pass through filters made of unglazed porcelain while the things that we recognize as microörganisms by other tests, such as visibility under the ordinary microscope, do not pass through. It is thought that

these filterable viruses may be a non-cellular form of life, and it is even suggested, though not generally accepted, that many of the ordinary bacteria may be capable of passing at times into such a state.

Since the bacteria are so small and their cells are so simple, morphology forms an insufficient basis for grouping them into genera and species, and their physiological activities are largely used as a basis of classification. One point so used is whether they do or do not ferment certain specific compounds (*e. g.*, glucose), and another is whether they do or do not liquefy gelatine when grown in cultures on this medium. Many other physiological activities form a more or less definite basis for classification. Some bacteria can oxidize inorganic compounds of sulphur or iron and can thus live wholly or partially independent of organic material, being thus quite different from other bacteria. Another general basis for classification is whether they require free oxygen or can grow in its absence. Those growing under the first condition are called aërobes, and those growing under the latter, anaërobes. A simple means of getting an indication of which of these groups an organism belongs to is to dip a sterilized needle into a culture of the organism and then thrust it into sterilized gelatin or other solid medium in a test-tube. If the organism grows best at the surface of this medium it is behaving as an aërobe, while if it grows best in the deeper portions infected it is behaving as an anaërobe. Not all bacteria are definitely aërobes or anaërobes, since some grow in either the presence or absence of free oxygen.

Many bacteria cause decay or putrefaction and are thus very useful to man in causing the disintegration of dead bodies and breaking up their complex materials into simple ones which may again take part in the life processes of plants and animals. *Bacillus subtilis,* known as the hay bacterium, is a common organism of this kind. Cultures are readily prepared by boiling a little hay in water and pouring off the infusion into a glass tumbler. The tumbler may be covered with a piece of glass. In a few days a scum will form on the surface of the liquid and in this the non-motile form of the organism will appear, while the motile form will

be found in the liquid. The cells are large enough to be seen with the high power of the ordinary microscope, but they are more plainly seen if stained with methylene blue or some other suitable stain. The cells often adhere end-to-end in chains, and in many of the older chains a spore is seen in each cell. These spores are capable of resisting the temperature of boiling water for an hour, and the organism in such a culture as this undoubtedly grows from spores.

Bacteria have great economic significance. Many diseases of man and of domestic animals as well as some diseases of cultivated plants are caused by them. Some bacteria also fix atmospheric nitrogen in the soil in forms in which it can be used by plants, while the physiological activities of others cause fermentations that are industrially important. These and other phases of the activities of bacteria are discussed in Chapter XXXII.

THE THREADY FUNGI (PHYCOMYCETES).

When we apply the name alga-like fungi to this group we are simply translating the technical name Phycomycetes, and they do resemble some of the green algæ rather closely in structure and reproduction. Their hyphæ are not united into a definite fruit body, and, though they have many nuclei, they have no cross walls. In having many nuclei and no cross walls these hyphæ resemble the filaments of such green algæ as *Vaucheria* and like them are called cœnocytes. Phycomycetes have sexual reproduction and are divided into two subclasses—Oömycetes (heterogamous forms) which have male and female gametes, and Zygomycetes (isogamous forms) in which the gametes are alike. A common water mold (*Saprolegnia*) and a white rust (*Albugo candida*) are examples of the Oömycetes, and the common bread mold (*Rhizopus nigricans*) and the squirting fungus (*Pilobolus*) are examples of the Zygomycetes.

A Water Mold.—*Saprolegnia* is a saprophytic mold which grows on organic matter in water and often occurs on the gills of fish in aquaria and on fish eggs in hatcheries. Specimens of it may be grown by placing a dead fly or a few very

minute pieces of bacon on the surface of a glass of water. The plants can sometimes be obtained by using tap water but better success usually follows if ditch water is used since impure water usually contains the spores of this plant in abundance. In a few days a mass of radiating hyphæ will appear on the fly or bacon and both sexual and asexual reproduction will be seen when this mycelium is examined under the microscope. The sporangia are club-shaped and are borne singly at the ends of the branches of the hyphæ. Each one produces numerous biciliate zoöspores which escape through a terminal opening and, after swimming about for a time, reproduce the plant directly or indirectly. The oögonia are round and usually produce several eggs, each having a single nucleus. A tube from the antheridium penetrates the oögonium wall and through it the male nuclei reach the eggs and fertilize them. The oöspore is a heavy-walled cell and when it germinates it produces the new mycelium directly. The egg cell, however, can germinate directly without fertilization, and this process, called parthenogenesis, is more common than fertilization.

Saprolegnia is thus seen to have three phases—vegetative growth, zoöspore production, and egg production. Vegetative growth is favored by growing the plant in ordinary tap water or lake water, while zoöspore production is likely to follow when the plants are transferred to distilled water. Lowering the temperature or transferring the plants from water to solid material is likely to be followed by the production of oöspores. The plasticity shown by this plant in response to changes in environment is somewhat similar to that shown by *Vaucheria* (see page 189).

A White Rust.—The mycelium of the white rust (*Albugo candida*) grows within the tissues of various parts of shepherd's purse and other plants belonging to the mustard family, such as cabbage and radishes, giving them a whitish, blistery appearance. The epidermis of the leaf or other part of the host plant is often forced up by the growth of the parasite and, being detached from the other tissues, dies. Conspicuous distortions of the organs of the host plant are often produced by this fungus. The mycelium grows among

the cells of the host tissues and penetrates them by haustoria. In the asexual reproduction numerous short branches called conidiophores are produced on the mycelium and from the end of each of these, spores called conidia are cut off in a row. These are blown about by the wind. Each conidium contains several nuclei and, when it germinates, produces a number of biciliate zoöspores, each of which quickly produces a new hypha, and may reinfect the host. Both oögonia and antheridia are multinucleate bodies produced within the tissues of the host plant. One male nucleus fuses with one female nucleus and the resulting oöspore, which is a resting spore used to tide the fungus over long periods of unfavorable conditions, may produce either zoöspores or a new mycelium. The conidial stage is more commonly found than the oöspore stage.

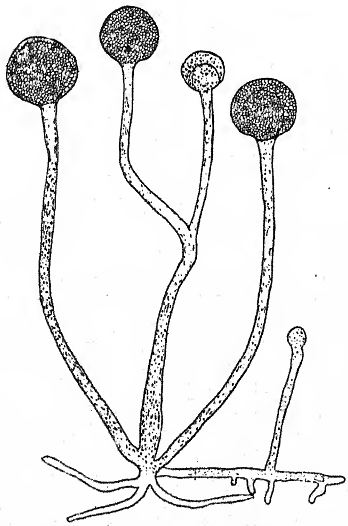

FIG. 93.—Bread mold, showing rhizoids, sporophores, and sporangia. A young sporophore is forming on the stolon at the right. (From Mansfield.)

The Bread Mold.—The bread mold (Fig. 93) forms a furry-white growth on moist bread kept in a warm place or on old fruit or other organic material. When spores are formed,

the whole mass looks black because of the color of the spores. The spores are commonly present in the air and a growth of the fungus may be secured without planting them. This plant is saprophytic and sends into the substratum branched portions of its mycelium, called rhizoids, which can, by the action of an enzyme (see page 154) produced by the fungus, dissolve the material with which they come into contact and thus render it capable of being absorbed by the fungus.

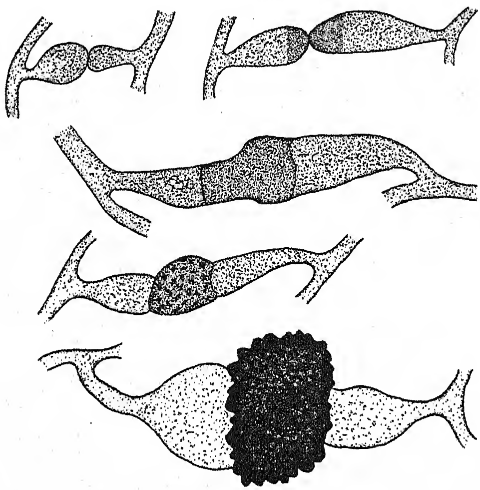

FIG. 94.—Stages in the formation of a zygospore in bread mold. See description of this process in the text. (Drawn by M. W. Phifer.)

Erect branches called sporangiophores are produced in clusters on the mycelium, and each bears a sporangium at its summit. The tip of the sporangiophore enlarges, becoming almost spherical, the protoplasm accumulates at the outer portion of this enlargement and is cut off from the more watery portion by a convex, almost hemispherical wall. This wall and its contents constitute the columella. The protoplasm between the columella and the outer wall now forms numerous cells, each having a wall around it. The contents of each cell then round-up and form a spore, and

the wall breaks down so that the spores are free in the sporangium. When a mature sporangium is mounted in water the wall usually bursts so that the columella with the spores scattered around it is the part usually seen. The spores produce a new mycelium directly.

Rhizopus is also reproduced by conjugation (Fig. 94). There are two strains of this plant (plus and minus), and where two hyphæ of different strains come into contact a special branch is produced on each. A cell cut off from the tip of each of these two branches functions as a gamete and the remaining portion of the branch is called a suspensor. When the two gametes fuse they form a thick-walled, black zygospore capable of resisting conditions that are unfavorable for growth. Under favorable conditions it germinates, producing an erect sporangiophore and the spores produced in the sporangium on this sporangiophore germinate, producing a new mycelium. The two strains of this plant are alike so far as vegetative appearance is concerned. The remains of the two suspensors are usually seen on the zygospore and they commonly differ in size, but the larger one has been found to come from either strain and the size of the suspensor does not furnish a basis for deciding which of the two strains is to be regarded as male or female.

This mold grows on apples, strawberries, sweet potatoes, beans and other fruits and vegetables in storage, starting on wounds or bruises and causing soft rot. A closely related mold (*Mucor*) grows on dung. When the word *Mucor* is written with a capital letter, it refers to this mold, but when written with a small letter it refers to any mold of the family to which both *Mucor* and *Rhizopus* belong.

The Squirting Fungus.—*Pilobolus* grows on stable manure and cultures of it are readily produced in dishes on horse dung. It is similar to *Rhizopus*, but has the remarkable power of hurling its sporangia away with considerable force, due to the swelling of the parts just beneath them. The sporangiophores are sensitive to light, and if the plant is grown in a dark box with a small glass window in one side, the glass is spattered with the black sporangia which adhere to it.

The Zygomycetes differ from the Oömycetes: (1) in usually having a more extensive mycelium and in having the aërial habit as opposed to the aquatic habit of the oömycetes; (2) in having non-motile asexual spores; and (3) in having gametes which are at least somewhat alike as opposed to the distinctly male and female gametes of the Oömycetes.

THE SAC FUNGI (ASCOMYCETES).

The sac fungi are characterized by having cross-walls in their hyphæ and having their asexual spores borne in a definite number, usually eight, in a thin-walled, sac-like body called an ascus. In many of them the mycelium spreads diffusely in the vegetative phase, but forms a definite body in the reproductive phase. In some species the hyphæ form a hard compact body called a sclerotium, which constitutes a dormant vegetative phase in the life history. The sac fungi comprise more species than any other group of fungi. Some of them are saprophytes, but many of them are parasites, causing diseases of higher plants. Some are highly prized as human food, some are poisonous to domestic animals, and one (*Ergot*) is used in medicine.

Some of the sac fungi have sex organs and unlike gametes, but in others these have not been found. When sexual reproduction occurs, the union of the male with the female nucleus is followed by the production of a definite body called an ascocarp, on or within which the asci are produced. This ascocarp corresponds to the cystocarp of the red algæ (see Fig. 90) and since the sex organs of the sac fungi are similar to those of the red algæ, a relationship between these two groups of plants is suggested.

Yeasts.—The common yeasts are one-celled plants reproducing by budding. There is a definite nucleus and a vacuole and fat droplets are usually seen. The cell wall is composed of cellulose. The cells are usually oval, and a small swelling, or bud, appears at one end, and continues to enlarge until it is finally cut off, forming a new cell. Cells formed by successive buds sometimes remain attached, thus forming short chains. Under certain nutritive conditions, cells

resembling asci are formed which contain a small definite number of spores. In the common yeasts no mycelium is present, though it is found in a few less common species. The yeasts are placed under the Ascomycetes, though only a few of them have any mycelium at all and spore reproduction occurs only under special conditions, because when a mycelium is present its hyphæ have cross walls and when spores are produced they are in a structure resembling an ascus.

Many yeasts have the power of fermenting sugars with the production of alcohol and carbon dioxide. An example of this is the fermentation of glucose represented by the equation

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{ethyl alcohol}}{2C_2H_5OH} + \underset{\text{carbon dioxide}}{2CO_2}$$

This fermentation is due to the presence of the enzyme, zymase, which acts on the sugar in the cell, the alcohol and the carbon dioxide then diffusing out into the bathing liquid.

The common edible morel (*Morchella esculenta*) (Fig. 95) is a saprophyte growing on soil in open woods and old orchards. It has a mycelium which spreads in the organic matter in the substratum and produces above ground a structure called an ascocarp, which is several inches high and consists of a hollow wrinkled oval body borne on a short stalk. The surface layer in the depressions on the outer surface of this body is a hymenium consisting of sterile filaments (paraphyses) and asci containing ascospores. When the ascospores germinate they produce the mycelium.

A Cup Fungus.—*Peziza aurantia* (see Fig. 95) is a common saprophytic cup fungus growing on soil in open places. Its mycelium grows in the organic matter of the soil and produces aërial, cup-shaped, orange-colored ascocarps, often an inch or more in diameter. The cup is lined with the hymenium, which consists of slender paraphyses and asci, each ascus producing eight oval spores. The development of the spores in this ascus is characteristic of the ascomycetes. At first it contains two nuclei. The origin of these nuclei has not been worked out in *Peziza*, but in *Pyronema*, a

closely related cup fungus, it has been found that the one is a male nucleus from an antheridium and the other is a female nucleus from an oögonium. The male nucleus enters the oögonium and several slender outgrowths are then formed from the oögonium and an ascus is formed on each of these outgrowths, one male nucleus and one female migrating to each ascus. These two nuclei fuse and their union constitutes fertilization. Some workers report a slightly different series of events from that described above, and the matter is still under discussion.

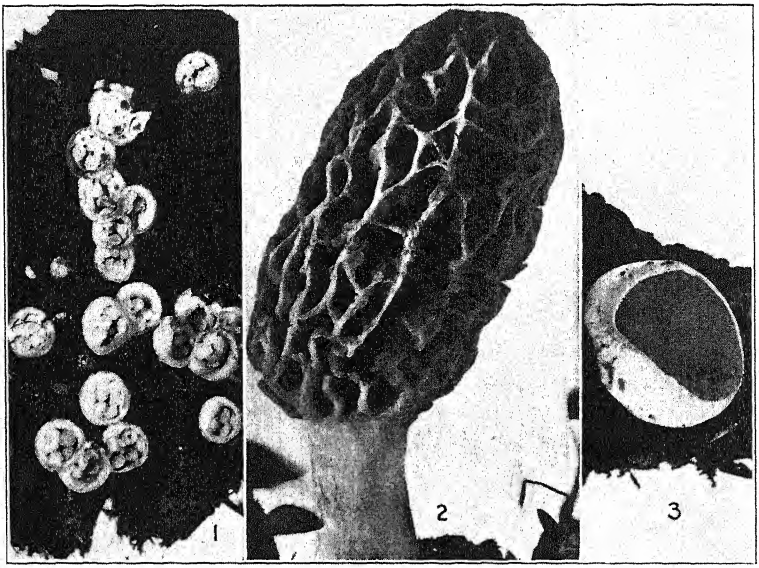

FIG. 95.—Fungi. 1, bird's nest fungus (*Cyanthus*); 2, morel (*Morchella*); 3, cup fungus (*Peziza*). (From Mansfield.)

After the fusion of the two nuclei the development of the spores in *Peziza* and *Pyronema* is the same. The nucleus resulting from the fusion divides, then each of these two divides, producing four, and these divide producing eight. A wall is formed around each of these nuclei in the last

division by the persistence and growth of the astral rays and eight spores are thus formed within the ascus. Not all of the cytoplasm is used up in forming these eight ascospores, and the young spores are embedded in the remaining cytoplasm. Much of this cytoplasm is used up in the growth of the spores, but even at maturity they are still embedded in some cytoplasm, which contains material that swells and eventually ruptures the tip of the ascus, liberating the spores. When the spores germinate they produce the mycelium.

The life history of the Ascomycetes as worked out fully in *Pyronema* suggests relationship to the red algæ, such as *Nemalion*, the ascocarp of the fungus corresponding to the cystocarp of the alga. The comparison is good up to this point but is weaker when we compare the ascospore of the fungus to the carpospore of the alga, since the former is an endospore formed within the ascus while the latter is an exospore formed by cutting off cells which are then naked within the cystocarp, and the carpospore thus corresponds more to a conidium than it does to an ascospore.

Truffles.—A saprophytic fungus called truffles, produces subterranean tuber-like bodies which are prized as human food. These bodies are the ascocarps, and they differ from the ascocarps of *Peziza* in being closed instead of open. The spores are borne in asci, but when the fleshy ascocarp is mature, the spores are free within it. The mycelium, like the ascocarps is subterranean. This plant belongs to the genus *Tuber* and the genus is most common in countries of southern Europe, though some species are occasionally found in the United States.

A Blue Mold.—*Penicillium* (Fig. 96) is a common saprophytic blue mold occurring on bread, lemons, cheese, and old leather. It has a loose mycelium and is reproduced mainly by conidia which are produced externally by being cut off successively from the ends of short branches clustered at the summits of the erect conidiophores. The conidia are scattered by the wind and produce new mycelia. The ascocarp phase of *Penicillium* is seldom seen, but is common in the familiar green mold *Aspergillus*, whose conidia are borne in characteristic rows radiating from the enlarged

summits of the conidiophores. The production of the ascocarp involves an alternation of generations, the sexual generation having organs that represent oögonia and antheridia. After fertilization a closed ascocarp is produced, in which are asci containing ascospores. The ascospores are later set free within this ascocarp and finally escape by its disintegration, and develop new mycelia.

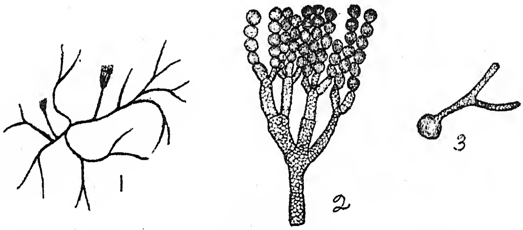

FIG. 96.—A blue mold (*Penicillium*). 1, habit sketch; 2, sporophore with conidia; 3, a germinating conidiospore. (Drawn by Charles Gray.)

A Mildew.—The lilac mildew (*Microsphæra*) is parasitic on the leaves of the lilac and sends absorbing organs into them. It produces conidia in great numbers and these scatter the disease. Later in the season the sex organs are produced and fertilization is followed by the production of closed ascocarps called perithecia (sing., perithecium). From the ascospores produced in these, the mycelium is reproduced the following year.

Ergot.—Ergot (*Claviceps purpurea*) is parasitic on rye and other plants of the grass family. The ovary of the flower of the host plant is infected by the mycelium which grows over it and produces conidia in clusters on short branches. Insects, attracted by a sweet substance produced by the fungus, carry these spores which infect other ovaries, thus spreading the disease rapidly. The mycelium penetrates the ovary of the host plant, finally replacing the grain entirely and producing a hard, dark-colored body, larger than the grain, called a sclerotium. Many of these sclerotia fall to the ground when the host plant is mature, and remain dormant until spring. The sclerotium then begins to grow and

produces several short stalks each bearing at its top a rounded body in which the perithecia are embedded. Each perithecium contains several asci, and each ascus contains eight slender ascospores. These ascospores are carried by the wind and germinate on the ovaries of the host, thus completing the life history. The sclerotium of *Ergot* is used as a medicine and is official in the United States. Cattle and other domestic animals are sometimes poisoned by eating ergot with the plants on which it has grown, and people have been poisoned by eating flour made from rye in which there were sclerotia of this fungus.

THE BASIDIUM FUNGI (BASIDIOMYCETES).

The basidium fungi are like the ascomycetes in having cross-walls in their hyphæ, but are different from them in having no functional sex organs, while many of the ascomycetes do, and in having their asexual spores borne externally on club-shaped processes called basidia. The basidium usually has four spores, each produced as a short outgrowth, into which a nucleus migrates from the basidium. Though a basidium does not look like an ascus, it resembles it in certain features of its development. When it is young it has two nuclei and these fuse just prior to the formation of the four nuclei, which migrate to the four basidiospores. It is not known whether this union is sexual, and no sexual organs at all are found in the higher Basidiomycetes. The four nuclei lie free in the basidium, and the outgrowth that is to form a spore begins when a nucleus comes near to the basidium wall.

Corn Smut.—Corn smut (*Ustilago maydis*) (Fig. 100) is well known in all regions where corn is grown, since the large black masses of spores are conspicuous on the ears, tassels, and other parts of the plant. The fungus is parasitic, and produces a mycelium which grows extensively in the tissues of the host, eventually producing a swelling in some part of the plant. Each cell of the hyphæ may develop into a spore, and the mycelium in such a swelling is practically all transformed into spores. This mass of spores covered by a thin

membrane formed by host cells and partially gelatinized hyphæ is popularly known as corn smut. The injury to the

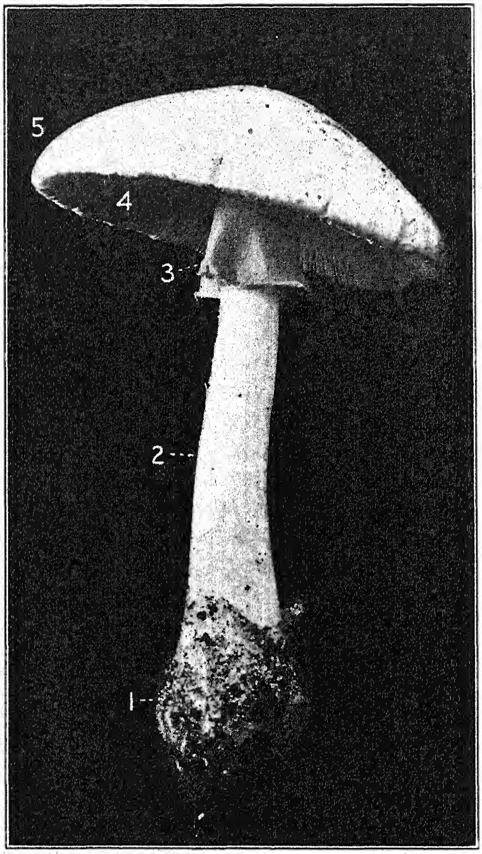

FIG. 97.—A gill fungus (*Amanita phalloides*). 1, remains of the membrane that enclosed the young stalk and cap; 2, stalk (stipe); 3, remains of the membrane that covered the gills; 4, gills; 5, cap (pileus).

host is most apparent when the mycelium fills the ovaries, thus often destroying the whole ear of corn and covering it with a mass of smut projecting from the husks. These

spores (chlamydospores) have thick walls, and when they fall upon the ground or other places they remain dormant until spring, when they germinate and produce a stage consisting of short filaments, usually not more than four cells in length.

These filaments produce spores from each cell of the filament, the development being the same as in other Basidiomycetes, and the spores then bud like yeast. If nutrition is abundant these spores are produced in enormous numbers. They infect the corn plants and thus spread the disease rapidly.

A Red Rust.—A red rust (*Puccinia graminis*) is parasitic on wheat and other plants of the grass family, and causes great economic losses. It produces rusty-looking red spots on the stems of the host plants in summer and this phase is called red rust. It also produces black spots later in the season and this phase is called black rust. In giving the life history it will be convenient to refer to the host plant as wheat, though it is also common on rye and barley.

Its life history is a complicated one since it produces four kinds of spores. Two of these are produced at different times on the same mycelium on the wheat plant, and another is produced on barberry leaves. Between the wheat stages and the barberry stage is another one which occurs on stubble or straw and sometimes on the ground.

The red spots on wheat stems are due to the production of the summer spores (uredospores). These spores are the reproductive phase of the mycelium which has grown extensively in the intercellular spaces of the tissues of the host. This mycelium produces numerous short sporophores, at the end of each of which a single spore is produced. These are scattered by the wind and when they lodge on other wheat plants they germinate immediately and produce a mycelium which penetrates the host and the disease is thus spread rapidly in summer.

The black spots appear on the wheat plants later in the summer, and are caused by the winter spores (teliospores) which grow on the same mycelium which earlier produced the summer spores. These black spots are pustules called telia

(sing., telium). The teliospores are two-celled, thick-walled resting spores which remain dormant on the ground or other places during the winter. They represent the same stage in the life history of this rust that the chlamydospores do in the life history of corn smut.

These winter spores germinate in the spring and produce a four-celled filament, called a promycelium, and from each of these cells a spore is produced on a very short stalk. This promycelium is a basidium and the spores produced by it are basidiospores, and the classification of *Puccinia graminis* as a Basidiomycete rests on this basis.

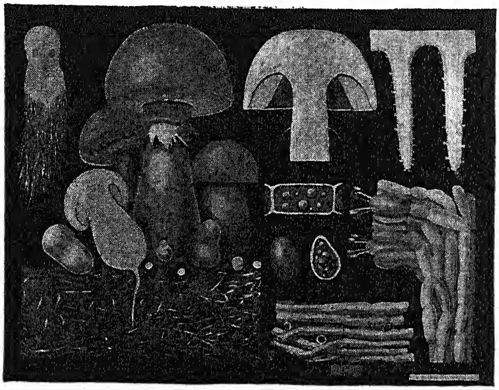

FIG. 98.—A common mushroom (*Agaricus campester*). Upper left, longitudinal section of young mushroom, showing hyphæ and an early stage of development of the plant body. Next, a group of mushrooms in various stages of development. Upper middle, longitudinal section of open mushroom, showing gills and remnants of ring. Upper right, cross-section of two gills with adherent spores. Lower right, section of gill, showing structure of gill and also showing two basidia, each with four spores. Lower middle, portion of mycelium from stipe. Above the mycelium, two spores, one in section. Above the spores, a cell from the tissue of the stipe. (From Schmeil Botanical Charts.)

These basidiospores are scattered by the wind, and when they lodge on the leaves of the barberry plants they germinate and produce a mycelium, which grows in the intercellular spaces of the leaf tissues. This mycelium produces cluster

cups (æcidia) on the lower surface of the leaf and these contain the æciospores. These spores are produced in rows by continued abstriction from the same cell, and the wall of the cup is produced by sterile cells formed in the same way. The æciospores are borne by the wind and may be carried long distances. When they lodge on a wheat plant they germinate and produce a mycelium which penetrates the tissues of the host, and the life history is complete.

Flask-shaped structures (spermagonia) occur on the upper surface of the barberry leaves at the same time or shortly before the cluster cups are formed on the lower surface. These are not functional but it is thought that they, with the cluster cups, may represent a degenerate sexual apparatus in which the spermagonia constitute the male elements and the cluster cups the female.

The cluster cup stage may apparently be omitted since this rust continues to flourish in regions where the barberry is not found, but it is not known just how the plant continues to propagate without this stage. It has been suggested that the rust does not really omit this stage but that the æciospores are borne by the wind to very great distances. It is possible that if this stage is really omitted, the rust may be kept alive by the survival of uredospores.

Two methods of combating wheat rust are in use—the eradication of the barberry and the development of rust-resisting strains of wheat. The barberry is a European shrub now common in many places in the United States, both wild and in cultivation. It is commonly thought that complete eradication of the barberry would at least help in controlling this disease, and many barberry plants have been destroyed for this reason. Some progress has been made in developing strains of wheat that are more or less resistant to the attacks of the fungus, and this is possibly a more hopeful line of attack than barberry eradication.

Rusts, such as wheat rust, which grow on alternate hosts, are called heterœcious rusts, while those that grow on only one host are called autœcious rusts. The white pine blister rust (*Cronartium rubicola*) is heterœcious and occurs alternately on white pine trees and on the black currant or some

other plant of the genus *Ribes*. It may occur on any of the pines that have five leaves in a fascicle, and it has done great damage in the United States since it was introduced about 1906. It attacks the cambium and inner bark and kills branches or whole trees. The principal means used for combating this rust is the eradication of cultivated black currants, wild currants, and gooseberries. Several rose rusts belonging to the genus *Phragmidium* are autœcious.

Bracket Fungi.—A bracket fungus (*Fomes pinicola*), also called a shelf fungus, is common on pines, the Douglas fir, and some other conifers. The bracket (Fig. 99) is a somewhat flattened, semicircular, horizontal body projecting from the bark of the tree, and when old may reach a diameter of almost 1 foot. It is anchored firmly to the tree, and large ones will sometimes bear the weight of a man. The upper surface is hard and convex, and thus sheds water and resists mechanical injury. The lower surface is creamy white and rather soft and has numerous pores. It is perennial and its upper surface shows ridges marking successive years of enlargement. If sawed in two vertically the perennial growth is also evident since layers, each marking a year's growth, are plainly seen. Each of the layers below the upper hard portion is marked by apparent vertical lines, which are really tubes into which the basidia project. The tubes open to the lower surface, and the spores borne on the basidia are discharged from them before they are covered by the next year's growth. The spores are borne by the wind and infect standing trees through wounds in the bark.

The vegetative phase consists of a mycelium growing extensively in the wood of the tree and finally producing the bracket which is the fruiting phase (sporophore). The growth of the mycelium soon injures the wood, giving it a punky character, which unfits it for use as lumber, and fir trees thus affected are called conchy fir. This fungus does great damage to standing timber and to logs on which the bark has been left.

Other species of the genus *Fomes* are found on various conifers and on deciduous trees, and cause the loss of much timber. Several species of the genus *Polyporus* are also

found on deciduous trees. Their sporophores are annual and rather thick and fleshy. Bracket fungi belonging to the genus *Polystictus* are common on deciduous trees and may be either parasitic or saprophytic. Their sporophores are usually annual and are thin and leathery.

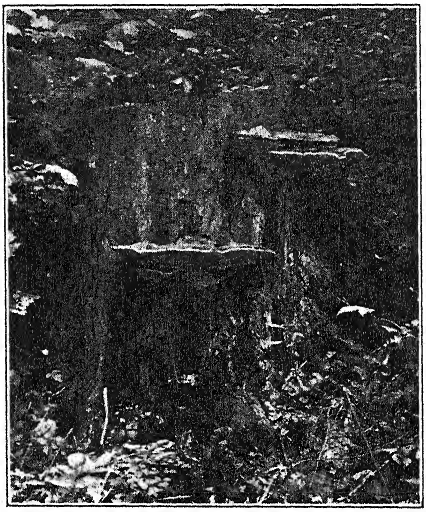

FIG. 99.—A bracket fungus growing on a dead stump. (From Mansfield.)

Gill Fungi.—The gill fungi (Fig. 97) are the common mushrooms and toadstools. They are very numerous and are the most familiar of the fleshy fungi. Many of the species of the genus *Coprinus* flourish on old dung, and other decaying matter, and the field mushroom (*Agaricus campestris*) is common. In such forms the mycelium grows extensively in the substratum and finally produces the spore-bearing phase. This is an aërial structure (Fig. 97) consisting of an erect stalk (stipe) with a cap (pileus) at the top. In the mature plant the cap has numerous gills projecting from its lower surface and on the surface of these gills are borne the basidia, each producing four spores (Fig. 98). The sporophore when very young is a button-like structure

(Fig. 98) and as the pileus develops and its lower portion breaks away from the stipe a ring (annulus) is often left around the stipe. When the spores germinate they produce new mycelia.

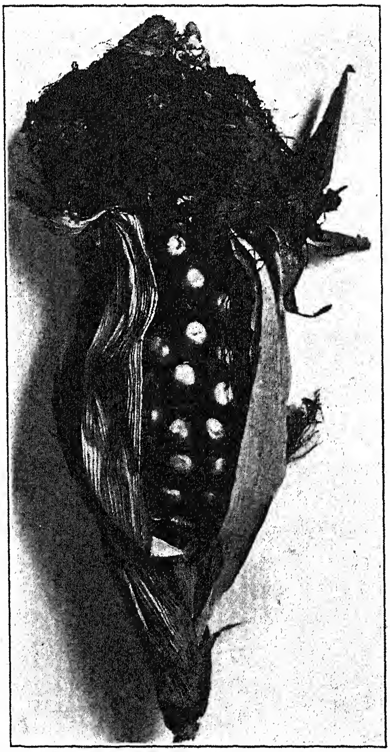

FIG. 100.—Corn smut growing on an ear of corn. (From Mansfield.)

Gill fungi frequently form "fairy rings" on lawns and other places by the extensive growth of the mycelium in the organic matter of the soil and the production of sporophores at the margin of this spreading mycelium.

Many of the gill fungi and of some other groups are edible, and many others are poisonous. It is best to consult some-

one who has definite knowledge of the matter before deciding on the use of any fungus as food.

Nidularia (Fig. 95) is a small nest-like fungus common on decaying wood and other matter. In the mature plant the spores are contained in small bodies which look like eggs in a nest.

THE IMPERFECT FUNGI (FUNGI IMPERFECTI).

The imperfect fungi are forms in which the life history is not fully known, which are placed together in this group merely because we do not know enough about them to classify them elsewhere. Several which were formerly placed in this provisional group have been transferred to other groups as their life histories became more fully known and perhaps others will be transferred as investigation goes on. Many of them produce conidia and are thought to be a phase of Ascomycetes, but others seem to be more probably related to the Phycomycetes or the Basidiomycetes. A number of diseases of economic plants, such as early blight of the potato, leaf blight of cotton, and fruit spot of apples are caused by imperfect fungi.

LINES OF DEVELOPMENT.

The fungi are not commonly regarded as being very significant in the evolutionary development of plants, though the possible relationship of some of them to certain algæ is interesting. They are usually considered as degenerate plants because they lack chlorophyll and must thus live as parasites or saprophytes and because the sexual organs are absent or imperfect in many of them.

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CHAPTER XV.

THE LICHENS.

A LICHEN (Fig. 102) is composed of two plants—a fungus and an alga. The plant body is a thallus in which the fungus forms the surfaces and the alga occupies the inner portion. The fungi that form all of the lichens of the temperate regions are sac fungi (*Ascomycetes*). A few species, mostly tropical, are formed by basidium fungi (*Basidiomycetes*). The algæ that enter into the formation of lichens are mostly green algæ, resembling *Pleurococcus*, though *Glœocapsa* and other blue-green algæ form the algal element of some. The alga may form a definite layer, with only a few fungal hyphæ extending through it (Fig. 102), or it may be scattered through the thallus. Some lichens have small outgrowths on the surface containing an alga different from the one within the thallus. Only a few of the lichens have common names, and the botanical names are generally used. Lichens are usually thought of as being moss-like, though they are morphologically quite different from the mosses, and the word moss is usually used in cases where common names are applied. The name reindeer moss is in general use for *Cladonia rangiferina*, and the name Iceland moss for *Cetraria islandica*, while long moss is a name used to include several species of lichens that hang from trees.

THE KINDS OF LICHENS.

The thallus of a lichen may have any one of five forms—leaf-like, erect, pendulous, crustose, or gelatinous—or it may show a transition between two of these, particularly between the first two. Leaf-like (foliose) lichens (Fig. 101) are common in temperate regions on soil, rocks, and old wood, and

are also often found on branches of trees and on top of dense growths of moss. Many of them are from 1 to 4 or 5 inches in diameter, though a few are larger than this and some are smaller. The surface of some of them is smooth, though in many species it is wrinkled or corrugated, and in some it has various kinds of outgrowths. Lichens are of various colors, such as green, grayish-green, ashy, black, or brown.

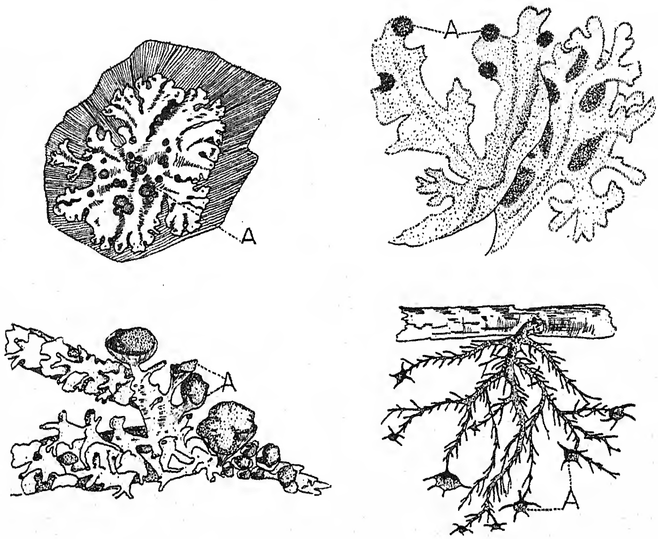

FIG. 101.—Lichens. Upper left, a thallose species (*Physcia sellaris*) with apothecia distributed over the surface of the thallus. Upper right, a thallose species (*Cetraria islandica*) with apothecia at the margin. Lower left, a fruticose species (*Bœomyces byssoides*) growing on a twig. Lower right, a filamentous species (*Usnea barbata*) growing on wood. *A* indicates apothecia in all cases. (Drawn by Ida Blanchard.)

The species that consist mainly of erect growths are common in northern regions. The one called reindeer moss is common on thin layers of humus over rocks, and also forms dense growths on the tundras of the northern portion of North America and the other continents. The one called Iceland moss is common in frigid regions, and is also found

in northern United States and in similar regions in other countries.

The pendulous ones are mostly somewhat thready in form and are abundant on the branches of trees in certain regions, especially in damp forests. In length they vary from a few inches to 2 feet or more, and they often give a very weird appearance to trees. The crustose lichens do not form a thallus that is readily removed from the surface on which it grows, but consist of an incrusting growth on, or even within, the substratum on which it occurs. They are common in many places on the bark of trees and are also found on rocks. One grows abundantly on the bark of alder trees, giving them a grayish appearance, and another is common on elm trees. Gelatinous lichens are not abundant, but are occasionally found in damp forests on tree trunks, wet rocks, and other objects.

THE STRUCTURE OF LICHENS.

The general structure of lichens is easily made out in the simpler leaf-like species. The genus *Peltigera* has a number of species, growing mostly on soil, though often found on rocks and old wood in forests or other damp places. They often grow so abundantly that they completely cover the substratum. The thallus is flat and is from 1 inch or less to several inches in diameter, and may be circular or fan-shaped, or it may be so much lobed as to be very irregular in shape. It is anchored to the substratum by rhizoids, which function also in the absorption of water, and dissolved substances. At its margin the upper surface shows several thickened areas, oval or round in shape, and varying from reddish-brown to black in color, called apothecia. The spores of the fungus are borne in these. In cross-section the green alga is seen in a layer in the interior of the vegetative portion of the thallus with a rather solid cortex formed by the fungus above it, and a looser mass of fungal hyphæ below it not covered by a cortex. In section (Fig. 103) the apothecia show the structure of the fruiting layer of an ascomycete fungus, such as *Peziza*. Sterile growths (paraphyses) and

spore-containing sacs (asci) are seen. The ascus is a slender structure containing 8 elongated spores, each consisting of a single row of from 4 to 8 cells. The alga is not found in the apothecia.

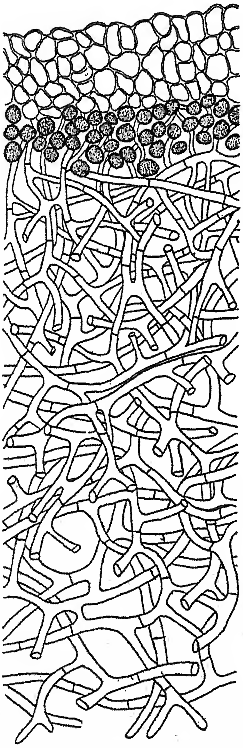

FIG. 102

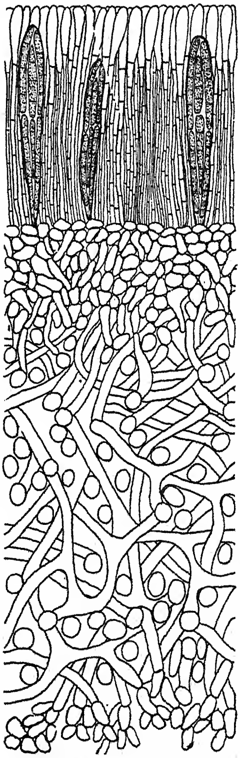

FIG. 103

FIG. 102.—Section of the thallus of a lichen (*Cladonia*), showing cortex (above) composed of closely arranged hyphæ, loosely arranged hyphæ (below), and algal layer with fungal hyphæ extending through it. Semidiagrammatic. (Drawn by M. W. Phifer.)

FIG. 103.—Section of a spore-producing area (apothecium) of a lichen (*Peltigera*). Top, fruiting layer (hymenium), consisting of sterile processes (paraphyses), and asci containing ascospores. Each ascus shows six spores and each spore is four-celled. Bottom, loose mass of hyphæ. Semidiagrammatic. (Drawn by M. W. Phifer.)

Another genus of leaf-like lichens (*Physcia*) (Fig. 101), which is common on trees, rocks, and old wood, and is also found on the surface of dense growths of moss, has a few species that produce erect branches and some that approach the crustose type. The thallus is from 1 to several inches in diameter, and its margin, though entire in some species, is much lobed in most of them. It has a cortex on both surfaces. The apothecia are scattered over the surface of the thallus, and the spores are two-celled in several species. In leaf-like lichens pores are often found extending from the surface to the interior of the thallus. Through these, exchanges of carbon dioxide and of oxygen between the outer air and that in the interior of the leaf occur by diffusion, and water is also evaporated. They are closed when the thallus is dry.

The partnership between the alga and the fungus in a lichen is evidently one in which there is mutual advantage. The advantage to the alga is protection and water supply, while that to the fungus is the supply of carbohydrate food. The alga gets protection from mechanical injury, from excessive loss of water, from great intensity of light, and probably also from sudden changes in temperature. The firm cortex formed by the fungus resists many rough contacts, such as those that occur when men or other animals walk over the lichens, which would otherwise injure the alga. Water evaporates slowly through this cortex, and the water supply of the alga is thus conserved. Water is also taken up by the fungus and held in and among the hyphæ of the lower portion of the thallus, and this supply can be drawn upon by the alga in photosynthesis. The upper cortex cuts down the intensity of the light reaching the alga, and thus probably often avoids injury to it, though this lowering of the light intensity must make photosynthesis less rapid.

THE REPRODUCTION OF LICHENS.

Lichens are reproduced in several ways. The most common one is by tangled masses of algal cells and fungal hyphæ, called soredia, which are produced on the surface of the

thallus, sometimes so abundantly as to form dry, powdery masses. When the soredia become detached each is capable of growing into a new thallus. Vegetative reproduction also takes place by fragmentation. Large or small pieces of the thallus become detached and blow away, and when they find suitable lodgment each may grow into a new thallus. It does not seem to be necessary that all of the portions of the thallus be represented in such a fragment, the essential thing being that both algal cells and fungal hyphæ be present. Lichens are also increased in number by the dying of older portions and the continued growth of lobes or branches which are thus separated. The spores of the lichen are the spores of the fungus, and if they germinate the reproduction of the lichen by this means must depend on chance contact with the algal cells. It does not seem probable that this method of reproduction is very common in Nature, though lichens have been experimentally reproduced in this way.

THE ECONOMIC IMPORTANCE OF LICHENS.

The most important direct economic use of lichens is their utilization as food. In certain parts of Alaska and in other northern regions they furnish the principal pasturage for reindeer, and they are also used as food by some animals in northern Africa. They have also been used as food by man in some places. Iceland moss is used as a medicine, and other lichens have been so used. Orcil, a violet or blue substance, is obtained from lichens and is used as a dye. Litmus, a substance giving a red color with acids and a blue color with alkalis, is obtained from a species of lichen, and is much used in chemical laboratories. Lichens often contribute to the formation of soils. They are in many cases the first plants to appear on rocks, and in the thin layer of humus thus formed mosses grow and afterward higher plants flourish. Lichens form dense growths on the branches of trees, especially in damp regions, and are often injurious to fruit trees. Spraying with lye or other solutions is often resorted to in getting rid of them.

Some prefer to classify the lichens under the fungi, since

the form of the thallus seems to be determined by the fungus and the fungus may be regarded as parasitic on the alga. On this plan most of the lichens would be classified as Ascomycetes, the others being Basidiomycetes. It seems better, however, in a general account of the plant kingdom to treat the lichens as a group of Thallophytes separate from both the algæ and the fungi, since the form of the thallus is usually quite different from that of any of the fungi, and the partnership between the alga and the fungus is of mutual advantage.

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CHAPTER XVI.

THE LIVERWORTS AND MOSSES (BRYOPHYTES).

GENERAL CHARACTERS.

THE Bryophytes comprise the liverworts and the mosses. They are mostly land plants growing in moist places, though a number of them are found in dry places and a few float on water or even grow submerged. They are small plants, but the individuals are numerous, and they frequently form a dense covering on soil, rocks, logs, and the trunks of trees. They are all green, and are thus able to make their own carbohydrate food, and none of them are parasites or saprophytes. The plant body varies from a flat thallus to a "leafy" stem. The differentiation into stem and leaves is, however, only in external form, and they lack the true differentiation into leaf, stem, and root which is characteristic of the two higher divisions—the Pteridophytes (fern plants) and the Spermatophytes (seed plants). There is no true conductive tissue in Bryophytes, the nearest approach to it being merely elongated cells.

Though the various Bryophytes differ so much in general appearance, they have certain features in common which distinguish them from the Thallophytes. One of these features is the obvious alternation of the sexual generation (gametophyte) with the asexual (sporophyte). In all cases the gametophyte is the more conspicuous generation, and is what we ordinarily call the plant, though the sporophyte is in many cases plainly visible. The sporophyte in all of the Bryophytes remains attached to the gametophyte, and is wholly or partially parasitic upon it. In many of them it contains chlorophyll, and is thus able to manufacture its own carbohydrate food, but it is still dependent upon the gametophyte at least for water. This alternation of generations in the Bryophytes is a true alternation characterized by the presence of the double (diploid) number of chromosomes

in the cells of the sporophyte and the single (haploid) number in those of the gametophyte. The doubling occurs in the union of the egg and the sperm and the reduction division (see p. 322) occurs in the formation of the asexual spores. Alternation of generations is, of course, found in many Thallophytes (*e. g.*, brown algæ, red algæ, and some fungi), but it is not universal in that division, and even when present it does not possess the uniformly evident character that it does in the Bryophytes.

Another feature that distinguishes the Bryophytes from the Thallophytes is the possession of many-celled sex organs. The egg-producing organ is a flask-shaped structure (archegonium) (Fig. 106), consisting of an expanded base called the venter, and a slender neck projecting from it, the egg being produced in the venter. This many-celled archegonium is clearly distinguished from the one-celled oögonium of the Thallophytes, and this is the best technical distinction between the two divisions. The antheridium is a rounded or club-shaped structure borne on a short stalk and consisting of a number of cubical cells surrounded by a wall one cell in thickness. Each of the cubical cells produces two biciliate sperms.

A third feature of the Bryophytes that is rather important from the evolutionary standpoint is the definite establishment of growth by means of an apical cell. Another feature that is universal in the Bryophytes is the distribution of the asexual spores by wind. This feature is, however, present in some Thallophytes, being found in many fungi. Most of the algæ are aquatic, and their spores are distributed by water.

The distinctions between the liverworts (Hepaticæ) and the mosses (Musci) can be more effectively stated after some plants of each of these classes have been described.

THE LIVERWORTS.

The liverworts comprise three groups—the Marchantiales, the Jungermanniales, and the Anthocerotales—each of which has quite distinctive characters.

The Marchantiales.—*Marchantia* (Fig. 104) is a familiar plant of the first group. It has a flat, dorsiventral, forked thallus, from 1 to 3 inches long and 1 inch or less in width, forming dense growths on damp soil. On the upper surface it shows a sort of mid-rib due to the elongation of the cells in its middle, and on the lower surface the rhizoids which attach it to the substratum are located mainly along the mid-rib. The thallus shows a differentiation of structure which correlates with its dorsiventral habit. The upper surface is divided into small diamond-shaped areas, with an open pore in the center of each. Beneath each pore is an air chamber, into which project short rows of cells containing numerous chloroplasts. This air chamber is continuous beneath each area, and is separated from the next one by a wall of green cells which supports the roof of the chamber. This roof is one cell thick except around the pore, where it consists of several layers of cells. The structure of the thallus thus allows contact of the moist green cells with an internal atmosphere, and permits the exchange of gasses between this internal atmosphere and the outer air as well as the escape of water vapor from the chamber to the outer air. The cells of the lower portion of the thallus contain few chloroplasts, or even none at all, and the rhizoids are outgrowth from the cells of the lower layer. The rhizoids are one-celled structures, and are of two kinds, one having thick walls with peg-like processes projecting into the cell from the wall and the other having thin walls without projections. The structure of the thallus thus provides for the absorption of water from the substratum and for passing it upward from cell to cell to the green cells where advantageous conditions for photosynthesis are present. The thallus grows in length and thickness by the cutting off of cells from three faces of an apical cell.

On the upper surface of the thallus there are cup-like structures (cupules, Fig. 104), in which are produced numerous disk-shaped bodies called gemmæ. These gemmæ are produced continuously, and the older ones are pushed to the top of the cupule by the development of the newer ones beneath, and thus escape and fall on the substratum near

by. Each gemma has two notches, one at each side, and these are the growing points from which develop two new thalli, by the continued cutting off of cells from an apical cell formed in each notch. The gemmæ provide a rather rapid means of vegetative reproduction for the thallus phase of the plant. A gemma is several cells thick, and its character is the same on both sides, its dorsiventrality being determined by light or other factors as it begins to grow into new thalli.

FIG. 104.—*Marchantia*, showing thallus, cupules, and antheridial branches.

The sex organs are borne on slender, erect branches, which at maturity are commonly about 2 inches tall (Fig. 105). Those producing the archegonia have at the top several radiating arms curving downward like the ribs of an umbrella. The archegonia project downward from these close to the stalk. The wall of the venter and the neck is one cell thick. In the development of the archegonium there is a row of cells within the neck, but as maturity

approaches these disintegrate, leaving an open passage to the egg in the venter through which the sperms enter. The egg is fertilized in the archegonium.

The antheridial branches (Fig. 104) have a lobed, disk-like structure at the top which contains numerous cavities, each with a small opening on the upper surface of the structure. Each cavity contains an antheridium. The sperms have cilia and can move from the antheridia to the archegonia only through water, but a thin film is sufficient. Fertilization takes place when the archegonial branch is very short and the necks of the archegonia are thus close to the surface

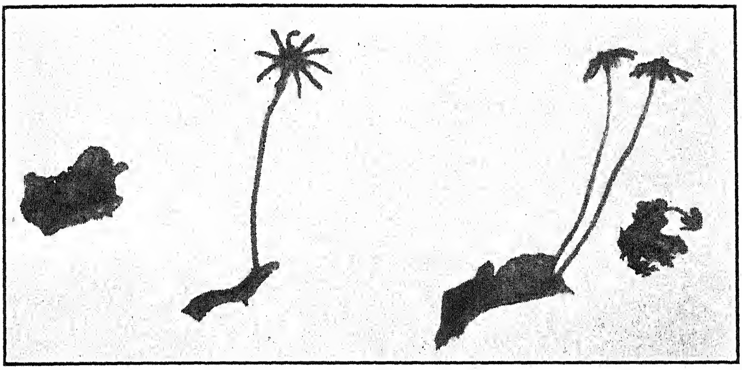

Fig. 105.—*Marchantia*, showing archegonial branches.

of the thallus. The fertilized egg germinates in the archegonium and produces the sporophyte (Fig. 107), which consists of a foot, a stalk, and a capsule, the foot being embedded in the tissue of the gametophyte. The capsule is oval in form, and has a wall composed of a single layer of cells. It contains numerous spores and also slender, spirally-thickened cells called elaters. At maturity the capsule breaks irregularly and discharges its spores. The elaters change form as they take in or lose water, and thus undoubtedly aid in loosening up the mass of spores. These spores produce the gametophyte, the first stage being a filament of cells from which the thallus grows.

The liverworts of the genus *Riccia* and of the closely related genus *Ricciocarpus* are smaller than *Marchantia* and are less common, but they show certain features that are important in understanding the general character of the Marchantiales. Some of them grow on damp soil, one usually floats on water, and one is usually submerged. All of them, however, are capable of growing on damp soil. The thallus of *Riccia* is somewhat similar to that of *March-*

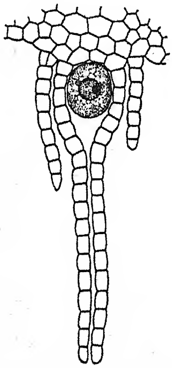

Fig. 106.—Longitudinal section of an archegonium of *Marchantia*, with the egg. (Drawn by E. C. Angst.)

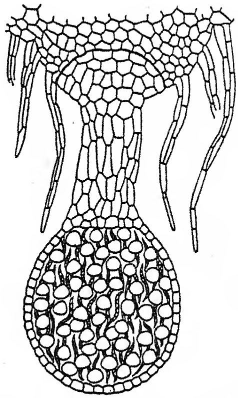

Fig. 107.—A sporophyte of *Marchantia*, showing foot, stalk, and capsule. Spores and elaters in capsule. The contact of the sporophyte with the gametophyte tissue above is marked by the curved line. (Drawn by E. C. Angst.)

antia in form, and is comparable to it in structure, though its upper surface has mere intercellular clefts instead of the pores and large chambers that characterize *Marchantia*. The archegonia and antheridia are borne in cavities in the upper portion of the thallus, each in a separate cavity opening to the surface. The sporophytes are within the cavities in which the archegonia grow. The sporophyte at maturity is spherical and consists of a capsule, there being no foot or stalk. The capsule has a wall one cell thick, and

contains numerous spores but no elaters. This is the simplest sporophyte found in the Bryophytes and is really nothing but a spore case.

The Jungermanniales.—The Jungermanniales comprise the leafy liverworts and also some thalloid ones. *Porella* (Fig. 108) is a common leafy one that forms dense masses of branched, leafy, somewhat pendant stems a few inches in length on the trunks and branches of trees in damp forests. Its gametophytes differ from those of *Marchantia* in showing considerable external differentiation of form, but little internal differentiation of tissues. The leaves show practically no differentiation of tissues and have no mid-rib. The plant is dorsiventral in structure, and there are three rows of leaves, two dorsal and one ventral, the dorsal ones usually having two unequal lobes. Vegetative reproduction occurs in two ways. One is by the death of the older portion of the stem and the survival of the branches, thus separated, and the other is by the formation of gemmæ at the margins of the leaves and the growth of these into new leafy plants when they are detached.

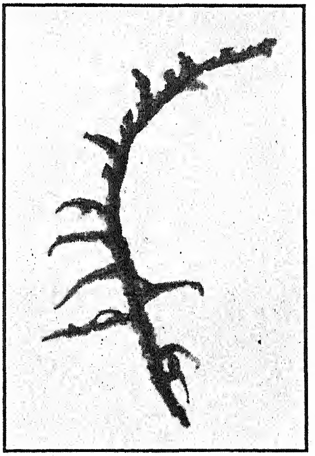

FIG. 108.—A portion of a leafy liverwort (Porella).

The archegonia are produced singly at the tips of branches, which resemble the ordinary vegetative branches in general appearance. Growth takes place by the division of an apical cell, and in the archegonial branches this cell produces the archegonium and the growth of the branch is thus terminated. The antheridia are stalked structures produced in the axils of small, closely imbricated leaves on very short branches.

The sporophyte consists of a foot, a stalk, and a capsule. The foot is embedded in the gametophyte tissue, and the stalk is slender and elongated so that the whole sporophyte

is an inch or so in length. The capsule contains spores and elaters, the latter being produced from a mass of cells extending into the capsule from the wall. At maturity the capsule splits into four valves and the spores are thus discharged. The leafy gametophytes are produced from these spores.

Some of the Jungermanniales (*e. g.*, *Aneura*) have a simple thallus, but resemble the leafy ones such as *Porella* in the character of the sporophyte and in the formation of the archegonium from the apical cell. The thallus of these plants is variously lobed, and the lobes of some of them approach the form of leaves so that they grade into the leafy ones.

The Anthocerotales.—The Anthocerotales are illustrated by *Anthoceros*. It has a thin, flat thallus, and frequently grows in such abundance as to form a complete covering on the soil on which it grows. The thallus shows comparatively little differentiation of tissue, and has the archegonia and the antheridia embedded in it. The archegonia are not in cavities in the thallus, as in *Riccia*, but the cells forming their walls are in actual contact with the vegetative cells of the thallus, and in this feature *Anthoceros* resembles the Pteridophytes.

The sporophytes are slender, erect, green structures, and when produced in large numbers from the crowded gametophytes they often resemble a dense growth of very small grass stems. The sporophyte consists of a foot and a capsule only, there being no clearly differentiated stalk. The foot is firmly embedded in the thallus. The capsule has stomates and these facilitate the formation of carbohydrate food in the green cells which form its outer portion. A striking feature of this sporophyte is the large amount of vegetative, or sterile, tissue and the small amount of spore-producing tissue. There are several layers of vegetative cells at the outside, and there is also a columella of vegetative cells in the center. Between these two is the dome-shaped layer of cells, some of which produce spores. Groups of sterile cells occur at intervals in this layer of sporogenous tissue, thus showing an approach toward the production of sporangia. Indefinite growth continues at the base of the

sporophyte and new cells, both sterile and sporogenous, are produced there while spores are being matured and discharged in the upper portion. The spores are discharged by the splitting of the top of the sporophyte into two parts.

Lines of Development.—The three groups of liverworts thus show different lines of development. The Marchantiales show gametophytes that are simple in their external form, but have considerable differentiation of tissues, and sporophytes that are relatively simple. The sporophyte of *Riccia* shows a minimum amount of sterile tissue and a maximum amount of sporogenous tissue, while that of *Marchantia* shows a larger proportion of sterile tissue and some differentiation in form. The Jungermanniales have gametophytes that show considerable differentiation of external form but little internal differentiation of tissues, and sporophytes whose capsules split in a definite way and also have a larger proportion of sterile tissue as compared with sporogenous tissue. The Anthocerotales have gametophytes that show little differentiation in either external form or internal structure, but have sporophytes with a very large amount of sterile tissue and a very small amount of sporogenous tissue, and even this is divided into separate regions by the intervention of groups of sterile cells. These characters, together with the presence of stomates, a large amount of green tissue, and of indefinite basal growth, make the sporophytes of the Anthocerotales decidedly the most highly developed ones of the liverworts. Since the sporophyte is the more highly developed generation in the Pteridophytes, it is evident that the Anthocerotales show the closest relationship to them, and this is the reason why they are placed highest in the morphological sequence of the liverworts.

THE MOSSES.

The mosses (*Musci*) are small, leafy, perennial plants growing in either wet or dry places or even in water. They are abundant on soil, logs, and tree trunks, and in many places they are common in lawns and pastures, and even on roofs and on masonry walls. Many of them are able to

withstand dry periods by becoming dormant and resuming growth when moisture is again available. There are three groups of mosses—the Sphagnales (bog mosses), all belonging to the genus *Sphagnum;* the Andreales (rock mosses), all belonging to the genus *Andrea;* and the Bryales (true mosses), comprising numerous families, genera, and species abundant in many regions and in a wide variety of habitats.

An understanding of the mosses as a class may best be given by first discussing the true mosses, since they are the most familiar ones, and then comparing the bog mosses and the rock mosses with them. It should be remembered, however, that the morphological sequence of the three groups is that given above.

The True Mosses.—The mosses that we most commonly see are true mosses. The genus *Mnium* has several species that are abundant on soil in moist woods and ravines. They have erect leafy stalks a few inches tall. One species (*M. Menziesii*) has its stems and branches covered with very small leaves, and bears a striking resemblance to very small trees, but most of the species have leaves $\frac{1}{4}$ inch or more in length scattered along the stem. The leaves on the lower portion of the stem are usually larger than those toward the tip. The leaves are flat and have a sort of mid-rib consisting merely of elongated cells. The stems have rhizoids which function as organs of absorption and anchorage. These leafy stems grow from buds formed on green alga-like filaments (the protonema) which spread over the soil. Growth continues in this moss, as in all the true mosses, from an apical cell.

The stems are of two kinds, the difference being apparent in the form and arrangement of the leaves at the tips. One kind (Fig. 109) has leaves of ordinary form radiating at the tip of the stem, and on the expanded end of the stem are borne the antheridia with the paraphyses among them, the mass formed by these being plainly visible. The antheridia are club-shaped structures producing numerous ciliated sperms.

The other kind of leafy stem has narrower leaves at its tip, and these are erect and closely overlapping. The arche-

gonia are borne on the stem tip enclosed by these leaves. They are similar to those of *Marchantia* in general form and in having neck canal cells which disintegrate, leaving an open passage down to the egg in the venter, but differ from them in being more slender, in having an elongated stalk below the venter, and in being more than one cell thick in the venter and at the base of the neck.

These two kinds of leafy branches and the protonema constitute the gametophyte generation of the moss. Fertilization takes place by the movement of the sperms down the neck and the union of one of them with the egg. The two kinds of stems grow together in the bed of moss, and a thin film of water is sufficient for the locomotion of the sperms.

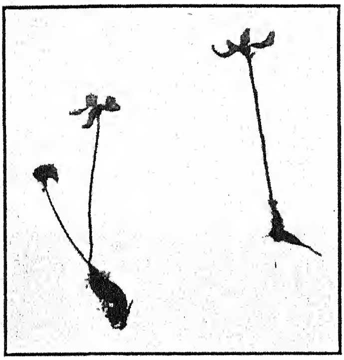

FIG. 109.—Antheridial stalks of a moss (*Mnium*).

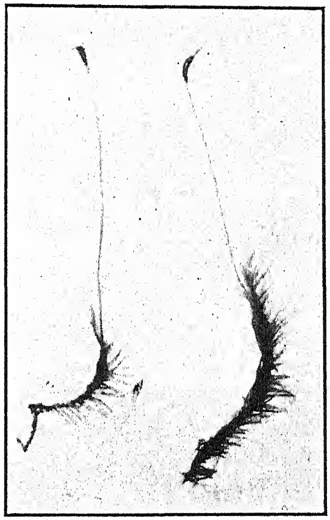

FIG. 110.—A moss (*Dicranum*), showing gametophyte (leafy stalk) with sporophyte (stalk and capsule) at top.

The sporophyte (Fig. 110) is produced by the germination of the oöspore (fertilized egg) in the venter of the archegonium. It has an erect stalk 1 or 2 inches in length, with a capsule at the top, and a foot which is embedded in the tissue at the end of the leafy gametophyte. More than one

sporophyte frequently occurs on the end of one stem. The mature capsule is either at a right angle to the stem or points a little downward. It is green when young and has some stomates. At its free end it has a loose hood-like cap of tissue called the calyptra, which is the remnant of the archegonium carried upward on the elongating sporophyte. Beneath this is a cap called the operculum which covers the end of the capsule, but is readily detached from it when the capsule is mature. Beneath the operculum there are two rows of slender teeth which project inward and cover the end of the capsule when they are moist, but curve outward and uncover the end of the capsule when they are dry, and thus allow the spores to escape. These teeth consist of dead cells with lignified walls. Comparatively few of the cells of the capsule are devoted to the production of spores, by far the larger portion of it being composed of sterile (vegetative) cells. There are several layers of sterile cells at the outside of the capsule, and inside of this is some spongy tissue, while in the center there is a columella. The spore-producing tissue is a single layer of cells between the columella and the spongy tissue, and is in the form of a hollow cylinder. When the spores escape they find suitable lodgment and germinate, producing the protonema.

Dicranum fuscescens (Fig. 110) also furnishes excellent material for the study of the life history of a moss. It is found in damp woods, and forms dense growths on decaying logs, rich soil, and the bases of tree trunks. Its stems are erect, yellowish-green, and are densely covered with narrow leaves. A stem usually bears only one sporophyte. The calyptra is so long that it is easily pulled off with the fingers, and the operculum has a long projection by which it is also readily removed. There are sixteen teeth and they are readily seen with a hand lens. The position of the antheridia and the archegonia, and the arrangement of the leaves around them is similar to that seen in *Mnium*.

The common hair-cap moss (*Polytrichum commune*) is a large moss growing in tufts on soil. The erect stems are stiff and several inches tall, and grow from a prostrate subterranean stem resembling a rhizome. They are densely

covered with narrow leaves, each of which grows from a sheath-like base. The stems are sometimes branched and the leaves have a "mid-rib." The antheridia are in a terminal cup, or disk, and from the center of many of these disks a new stem grows up after the antheridia are mature. The archegonial stems have erect, imbricated leaves at their tips and are readily distinguished from the antheridial ones. The sporophyte is often more than 2 inches tall, and the

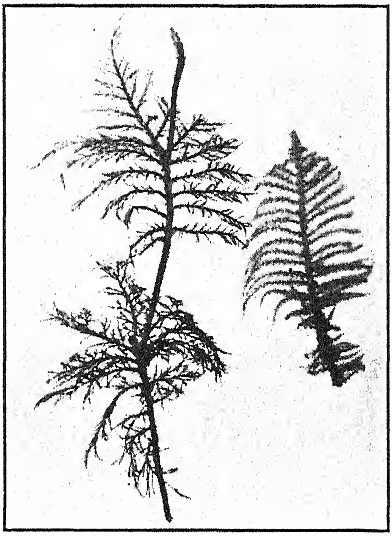

Fig. 111.—Left, feather moss (*Hylocomnium splendens*), showing three years' growth. Right, a prostrate moss, showing axis and leafy branches.

capsule, when ripe, is reddish-brown and forms approximately a right angle with the stalk. The capsule is four-angled and is almost completely covered by the large brown calyptra, which is composed of hairs ending freely at the bottom. When this is removed the short-beaked operculum covering the end of the capsule is seen. The teeth, exposed by the removal of the operculum are 64 in number, and their ends remain attached to the columella, forming a sort of pepper

box, from which the spores are sifted. When the capsule is moist the spaces between the teeth are closed, and when it is dry these spaces are open. Several other species of hair-cap mosses, also called bird wheat, or pigeon wheat, are common, and the calyptra of some of them is whitish.

The cord moss (*Funaria hygrometrica*) is very abundant on soil, especially where stumps or other materials have recently been burned. It is a small moss with a tuft of crowded leaves at the top of the stem. The capsules are unsymmetrical and are brown when old. The stalks of the sporophytes are cord-like and twist up when dry and untwist when moist.

Vegetative reproduction is common in mosses. Some have bulbils which grow directly into leafy stems, and others have bodies that produce a protonema. The bulbils may be very simple or they may be quite complex bodies, showing rudiments of stems and leaves. In some species of *Aulacomnium* the protonema-producing bodies are borne in a cluster at the top of an erect stalk at the summit of the leafy branch. The leaves of some mosses, when dry, break up and the pieces grow into new leafy plants.

The Bog Mosses.—The bog mosses (*Sphagnum*) (Fig. 112) are quite different from the true mosses (Bryales) in habitat, in appearance, and in the structure of both the gametophyte and the sporophyte. They form extensive growths in damp places in cooler regions, the entire surface of the substratum being composed of the living moss and dead remains underneath, being frequently 2 or 3 feet thick. In this substratum of living and dead moss other plants, especially certain small shrubs, grow, and in the older stages, when the moss at the surface is mostly dead, forest trees attain considerable size. Places where the substratum is composed of living or dead bog mosses are called *Sphagnum* bogs, and the mosses often form tussocks of considerable size, and may even grow so extensively that the center of the bog is raised several feet above the margin.

When growing, the plants are mostly green, grayish-white, or reddish-brown. The stems are branched, and both stems and branches are very leafy. The leaves have no mid-rib,

and are only one cell thick, and are composed of two kinds of cells—large colorless empty ones (hyaline cells) and long narrow green ones. The green cells alternate with the hyaline ones, and are so narrow that at first sight they might be mistaken for the walls of the hyaline cells. The walls of the hyaline cells are strengthened by circular bands inside and have pores through which water may pass in and out. In the outer portion of the "stems" of some species there are cells similar to the hyaline cells of the leaves. These hya-

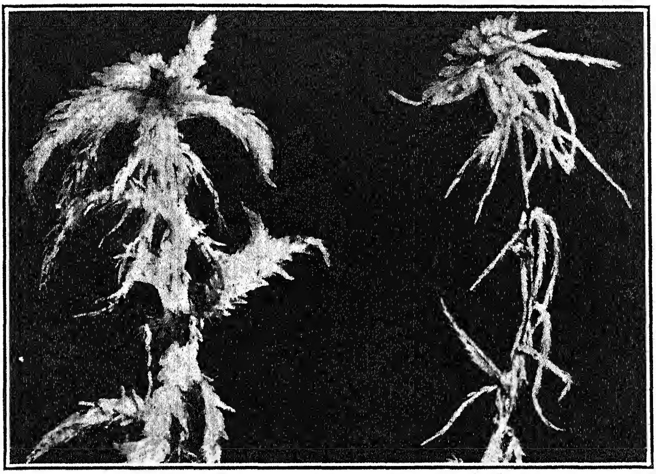

FIG. 112.—Peat mosses. Left, *Sphagnum palustre*. Right, *S. fuscum*. (From Hotson.)

line cells take in and hold considerable water, and bog moss brought in from the field often loses over 80 per cent of its weight in complete drying. Vegetative reproduction occurs by the death of the older portion of the stem and the continued growth of the branches thus separated.

The antheridia and the archegonia are borne on separate branches. The sporophyte is a rounded body, black when ripe, elevated an inch or less on a stalk, which is a part of the gametophyte, and consisting of a foot and a capsule, but

no stalk. It has an operculum and a calyptra, and the sporogenous tissue is dome-shaped and four cells thick. When the spores germinate they give rise to a short filament, from which is produced a flat structure somewhat resembling the thallus of the liverworts, and from this the leafy gametophyte stems arise. This thalloid phase of the gametophyte is quite different from the protonema of the true mosses.

The Rock Mosses.—The rock mosses (Andreales) grow in dry places. They have some morphological features resembling the true mosses, some resembling the bog mosses, and others resembling the leafy liverworts. The first phase of the gametophyte has three forms—filaments, a plate, and a cylindrical mass of tissue—and leafy branches may arise from any of these. When they arise from the filaments a resemblance to the true mosses is seen, when from a plate a resemblance to the bog mosses, and when from the cylinder no resemblance to either one. The sporophyte resembles that of the bog mosses in having the spores produced in a dome-shaped region, and in being raised on a stalk which is a part of the gametophyte. The sporophyte differs from that of all of the other mosses, however, in having no operculum, the spores being discharged through four slits.

Distinctions Between Mosses and Liverworts.—It is not easy to state any one character which may be used to distinguish the mosses from the liverworts, but combinations of characters do distinguish them, and when one becomes fairly familiar with the two groups it is not difficult to decide to which group any plant that is found belongs. The liverworts have a flat thallus or a leafy shoot which is nearly always dorsiventral, and the protonema is inconspicuous and poorly developed. Nearly all have elaters, and a columella is found in the sporophyte in the Anthocerotales only. The mosses are all leafy, and their stems are usually erect and the leaves spirally arranged. A few, however (Fig. 111), grow flat on the substratum and have an appearance of bilateral symmetry. The protonema is mostly well developed, the capsule in all mosses has a columella, and none have elaters.

Lines of Development.—Since it is the sporophyte that is most important in tracing the relationship of the Bryophytes to the Pteridophytes, it is evident why the mosses are placed above the liverworts. The sporophyte of the mosses is more complex than that of the liverworts and shows a much greater degree of differentiation, especially of cells related to protection, food supply, and dissemination of spores, and this shows progress toward the Pteridophytes. It must be remembered that the complexities of the gametophytes of the Bryophytes do not show important relationship to the Pteridophytes, since the gametophytes of the latter are much reduced and the sporophyte is the conspicuous and highly differentiated generation.

Suggestions for Further Reading.

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CHAPTER XVII.

THE FERNS AND THEIR CLOSE RELATIVES (PTERIDOPHYTES).

THE Pteridophytes are the common ferns and their close relatives. In size they vary from a floating water fern showing only a few small leaves to the tree ferns which may reach a height of 25 feet or more. In temperate regions the Pteridophytes most frequently seen are the common ferns, such as the Christmas fern (Fig. 150), the licorice fern, the the maidenhair, and the bracken (Fig. 113). All of the plants that are essential to a general understanding of the division are included in five orders—the Lycopodiales (club mosses and moss ferns), the Isoetales (quillworts), the Equisetales (horsetails, or scouring rushes), the Ophioglossales (*e. g.*, the grape ferns), and the Filicales (true ferns and water ferns). All Pteridophytes have true stems and leaves, and, with rare exceptions, they have roots also. The roots, stems, and leaves of most of them grow by the continued division of a single apical cell one for each branch, instead of from a meristem of several cells, as those of the seed plants do. All of them show alternation of generations, the leafy plant that we ordinarily see being the asexual generation (sporophyte), and the sexual generation (gametophyte) being smaller and less conspicuous. The sporophyte has true conductive tissue, and in this and in other vegetative structural characters it resembles the sporophyte of the seed plants. The sporophyte begins its life history attached to the gametophyte, but soon becomes independent of it by sending its own roots into the soil and expanding its own green leaves to the air, or in rare cases in water. The two generations are characterized by the 2x (diploid) number of chromosomes in the cells of the sporophyte and the x (haploid) number in those of the gametophyte. The diploid number is 90 in one common fern and 128 in another. Other chromosome numbers are found in other ferns.

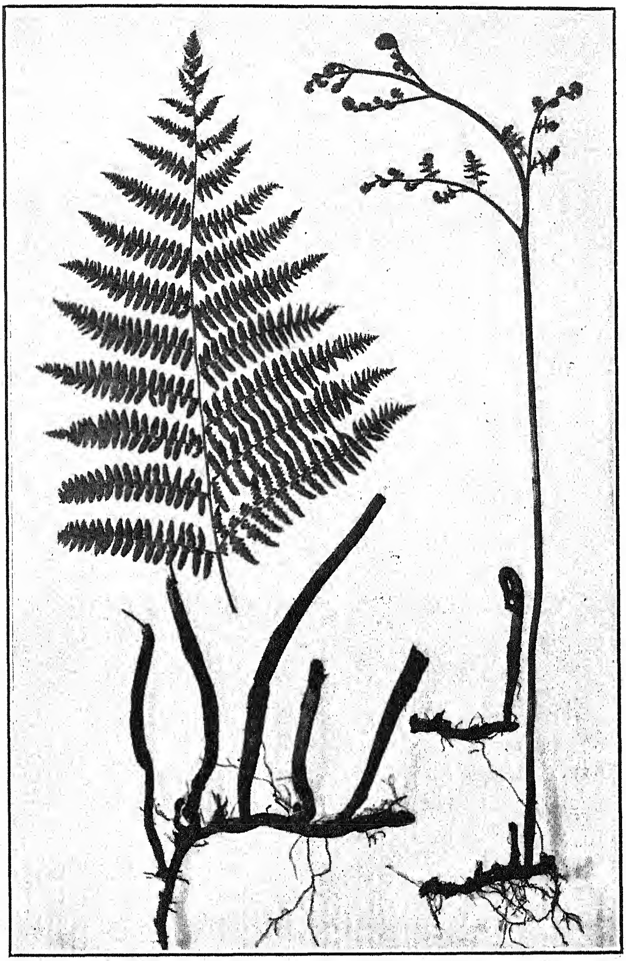

FIG. 113.—The bracken fern (*Pteridium aquilinum*). Upper left, portion of a leaf. Lower left, portion of a rhizome with roots and bases of old leaves. Right, a young plant with leaf, rhizome, and roots. At left of young plant, a leaf at the stage that it breaks through the soil, showing unfolding with growth.

SOME COMMON FERNS.

The general character of the Pteridophytes may best be made clear by describing some common examples of the true ferns and then comparing the plants of the other three classes with them. It should be remembered, however, that the commonly accepted morphological sequence of the five orders is that given above. The common brake, or bracken fern (*Pteridium aquilinum*) (Fig. 113) is widely distributed in the United States and other countries. It is a vigorously growing, hardy fern less than 2 feet tall in many localities, but

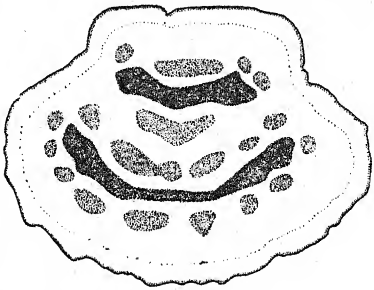

FIG. 114.—Diagrammatic cross-section of rhizome of common brake (*Pteridium*). Outside of dotted line, cortex composed mainly of sclerenchyma. The two heavily shaded portions are mechanical tissue (sclerenchyma). The stippled areas are vascular bundles. The remaining portion is storage parenchyma. (Drawn by M. W. Phifer.)

reaching a height of 8 feet or more in others. The stem is entirely underground and the aërial portion consists of one or more leaves arising from this and coming from the soil singly. The stem is a branched, dark-colored, horizontal rhizome, sometimes reaching a diameter of 1 inch, but usually much smaller. It may reach a length of several feet, and is usually 6 inches or so under the surface of the soil, though portions of it are sometimes found growing at a depth of 2 feet or more. The surface is hard and breaks readily when bent sharply, but some of the interior portions are tough and pliable. It grows from the tips and the older portions die.

This rhizome is easily cut in two with a knife, and on the cut end three tissues are readily distinguished—a hard tissue (sclerenchyma), a soft tissue (parenchyma) and the vascular bundles (Fig. 114). The sclerenchyma is composed of closely

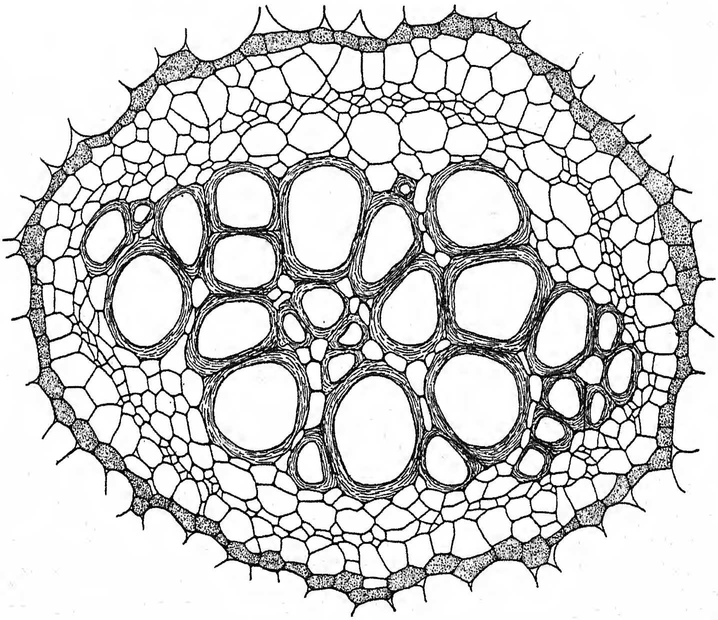

FIG. 115.—Cross-section of vascular bundle of common brake. The central portion (xylem) is composed largely of tracheids. These show large lumen and thick walls, with middle lamella between them. The thin-walled cells among the tracheids are parenchyma. The endodermis is the layer of darkened cells surrounding the bundle. Just within this is the pericycle consisting of one or more layers of cells. Next to the xylem are the large, thin-walled sieve tubes. Between the sieve tubes and the pericycle are some smaller cells with thicker walls. (Drawn by M. W. Phifer.)

packed cells with thick lignified walls. It covers the entire surface and is also found in the interior. In the cross-section two dark-colored masses of sclerenchyma, one straight and the other curved, are usually seen, though the two are often fused, forming a roughly circular figure flattened at one side.

When the rhizome is torn to pieces these bands of sclerenchyma are found to be strong and pliable, thus differing from the external cortical sclerenchyma, which is hard but brittle. Very small scattered masses of sclerenchyma are also seen in the cross-section. The parenchyma is soft and white, and forms the main bulk of the rhizome. Storage is a large function of this parenchyma, and its cells contain numerous starch grains.

The vascular bundles are brown in color, and in cross-section they appear in two series, one series outside of the sclerenchyma masses and the other series between the masses or within the circle formed by their fusion. The bundles are variable both in number and in the form of their cross-section. There may be as many as ten or more in the outer series, and they are usually circular or oval in cross-section. There are fewer, frequently two or three, in the inner series, and they are commonly in the form of elongated ovals in cross-section.

Each bundle (Fig. 115) has the xylem in the center surrounded by the phloem. The whole bundle is surrounded by an endodermis composed of a single layer of cells, and within this is a pericycle a few cells thick. The xylem is composed mainly of large tracheids, flattened where they are in contact with one another. Their walls are thick and lignified. Groups of smaller tracheids are present among the larger ones. In the development of the bundle these are formed before the larger ones and they constitute the protoxylem, the xylem formed later being called the metaxylem. The metaxylem develops in all directions, leaving the protoxylem strand centrally located in the mature bundle. The tracheids of both the xylem and the protoxylem consist of a cell wall and lumen only, the living protoplast having disappeared. There is also some parenchyma in the xylem, and this is usually continuous with the parenchyma in which the sieve tubes are embedded. There is usually only one row of sieve cells, and they have thin walls and are larger than the cells of the parenchyma of the bundle. The phloem lacks the companion cells which are characteristic of the phloem of the bundles of seed plants (Fig. 19).

All of the tissues described are seen also in a longitudinal section of the bundle (Fig. 115). Each tracheid is a single cell, several times as long as broad, and having oblique end walls. A few of the pits in its wall are almost circular, but most of them are transversely elongated, giving the whole cell a somewhat ladder-like appearance. Because of this appearance they are called scalariform tracheids from the Latin word "scala," meaning a ladder. The sieve cells taper at the ends, and their walls are marked by numerous sieve plates which are common to the walls of two cells lying

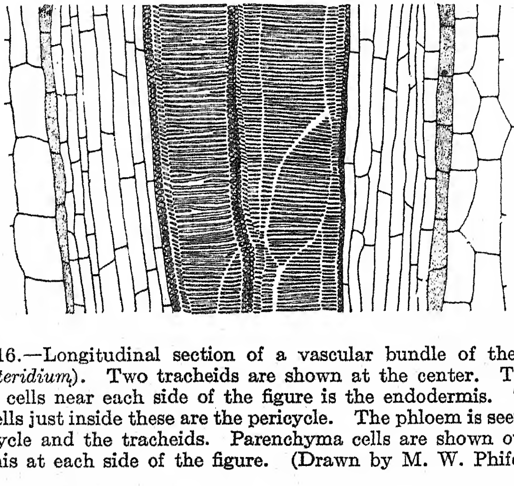

Fig. 116.—Longitudinal section of a vascular bundle of the common brake (*Pteridium*). Two tracheids are shown at the center. The row of darkened cells near each side of the figure is the endodermis. The three rows of cells just inside these are the pericycle. The phloem is seen between the pericycle and the tracheids. Parenchyma cells are shown outside the endodermis at each side of the figure. (Drawn by M. W. Phifer.)

against each other. The contents of the sieve cells are watery and are not seen in either the longitudinal section or the cross-section.

The rhizome has long slender roots, each having a central strand of vascular tissue composed of xylem and phloem, which is surrounded by parenchyma tissue extending to the endodermis, outside of which is a cortex composed of thick-walled cells. The growing tip of each root is covered by a cap, and back of this there are root hairs which are outgrowths from the surface cells.

The leaf of the brake (Fig. 113) is large and much branched. The long erect stalk usually branches into three parts, and

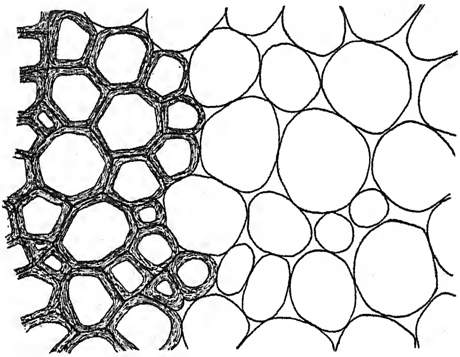

FIG. 117.—Cross-section of portion of sclerenchyma (right) and parenchyma (left) of rhizome of common brake. (Drawn by M. W. Phifer.)

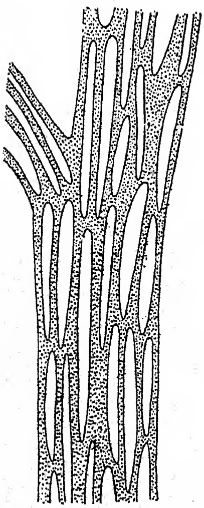

FIG. 118.—Diagrammatic longitudinal section of rhizome of common brake, showing intercommunications of vascular bundles. (From Angst.)

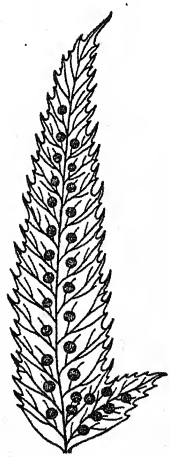

FIG. 119.—A leaflet of the sword fern (*Polystichum munitum*), showing venation and sori. (Drawn by E. C. Angst.)

these again branch, the ultimate branches bearing numerous pinnately-arranged leaflets, each having many pinnate lobes. The vascular bundles of the petiole originate from those of the rhizome, and their branches extend into the parenchyma tissues of the leaflets. The leaflets have an epidermis with stomates, and the parenchyma occupying the interior has many intercellular spaces. The leaves die in the fall and new ones come up in the spring, with their tips coiled (Fig. 113) and unfold as they grow.

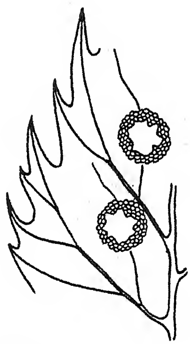

FIG. 120.—Detail of a portion of a leaflet of sword fern, showing the indusium of two sori, with sporangia projecting from under them. (Drawn by E. C. Angst.)

The spores of the brake are borne in sporangia (Fig. 122), which form a row around the lobes of the leaflets on the under side, and are covered by the modified margin of the lobes. A membranaceous covering for sporangia is called an indusium, and where it is formed by the margin of the leaflet it is called a false indusium to distinguish it from a true indusium which will be described later.

The sporangium is a stalked structure with a spheroid spore case, having a row of thick-walled cells extending over it called an annulus. The annulus begins at the base of the spore case and extends vertically over the top, but not quite to the base on the opposite side. When the sporangium is mature the annulus straightens out as it dries, and the wall

of the spore case is ruptured on the side where the annulus is not complete, discharging the spores. As the drying con-

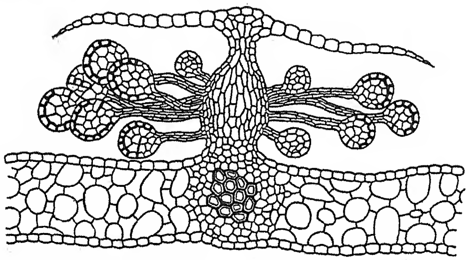

FIG. 121.—Cross-section of leaf and sorus of sword fern, showing sporangia and indusium. (Drawn by E. C. Angst.)

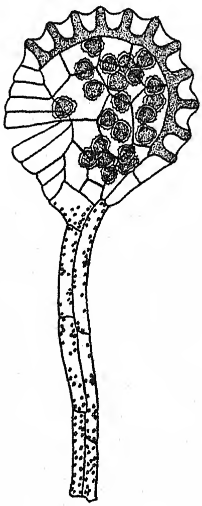

FIG. 122.—A fern sporangium, showing spores and ring (annulus). (Drawn by E. C. Angst.)

tinues, the annulus finally snaps back to its former curved shape and the spores are thus often thrown forcibly out. The sporangium is developed by the continued division of

an outer cell of the leaf tissue, and this kind of sporangium development (leptosporangiate) is characteristic of most of the true ferns as distinguished from the eusporangiate development (*i. e.*, from an inner cell, see p. 278) of the sporangium of some other Pteridophytes.

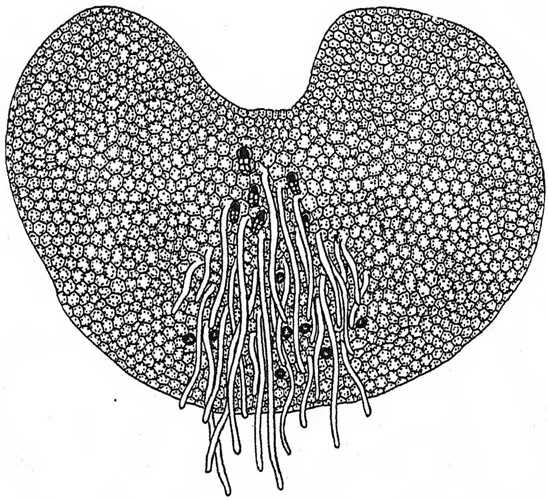

FIG. 123.—Lower surface of a prothallus (gametophyte) of a fern. Archegonia are shown near the notch, and antheridia below. Rhizoids are also shown. (Drawn by E. C. Angst.)

The spores grow into the gametophyte generation, called a prothallus (Fig. 123), which is a green, heart-shaped structure, usually less than ½ inch in diameter, growing flat on the substratum. The prothallia of other common ferns are similar to those of the brake, and fern prothallia are common in damp shady places on soil and decaying wood, and are often formed on flower pots or soil in greenhouses. When the spore germinates it first produces a filament of cells, and the prothallus grows from this. The prothallus has rhizoids, but otherwise shows little differentiation of its vegetative tissue. The antheridia and the archegonia are borne on its under surface (Fig. 123), the former on the older portion

near the rhizoids, and the latter on the newer portion near the notch. The antheridia are dome-shaped structures producing spiral, multiciliate sperms which move through a film of water to the archegonia. The venters of the archegonia are embedded in the prothallus, and their necks curve backward toward the antheridia. The neck canal cells disintegrate, as in the Bryophytes, leaving an open passage to the egg in the venter. The sperms enter through this passage and one of them fuses with the egg, forming the oöspore, from which the sporophyte is produced. Though there are several archegonia, only one mature sporophyte is commonly produced from a prothallus. The young sporophyte grows upward past the edge of the gametophyte at its notch, and after a short time becomes independent of it and the gametophyte then dies.

The Christmas fern (*Polystichum acrostichoides*) has its leaves in clusters, each cluster coming from a short rhizome. The newer portion of the rhizome is so thickly covered with the bases of living leaves, and its older portion with the bases of dead leaves, that it is usually seen only when these are cut away. The leaves remain green through the winter, though they often recline on the ground because of the weakening or even decay of the softer tissues at the base. They are much used for winter decorations. They often reach a height of 3 feet and the leaflets are pinnately arranged. The sporangia are borne in round dots called sori (sing., sorus) on the backs of the leaflets. The sori are commonly found on the leaflets toward the upper end of the leaf, the leaflets toward the base being sterile. There are usually two rows of sori on a leaflet, one on each side of the midrib and parallel to it (Fig. 119). Each sorus is covered by a membranaceous indusium attached at its center and free at the margin (Fig. 121). A special covering such as this is called a true indusium, to distinguish it from the false indusium seen in the brake and some other ferns. The sporangia are similar to those of the brake, and the life history is essentially the same.

The sword fern (*Polystichum munitum*) (Fig. 150), an

evergreen fern common from Alaska to Idaho and California, is also often called a Christmas fern. Its leaves, often as much as 4 feet long, are very leathery and are much used for winter decorations. Like the eastern species, it is very hardy and it is often transplanted to gardens.

The ferns described belong to the family Polypodiaceæ, which includes most of the ordinary ferns of the temperate regions. The members of the family differ a good deal in the size and form of their leaves and in the way that the sporangia are borne. The rock brakes (*Cryptogramma*) are low, tufted plants with two kinds of leaves, one kind (fertile) bearing sporangia, and the other kind (sterile) being vegetative only. The leaflets of the fertile ones are narrow, and have their margins inrolled, while those of the sterile ones are somewhat broader and are flat. The deer fern (*Lomaria*) shows a still greater difference between the sterile leaves and the fertile ones. The former are pinnate green leaves about 1 foot long, tending to recline on the substratum, while the latter are slender, erect, plume-like leaves reaching a height of 2 feet, less conspicuously green when mature, and performing mainly the function of spore-bearing. The maidenhair (*Adiantum*) is a delicate fern growing in damp, shady places, with dark-colored, shiny leaf stalks and numerous leaflets. The sporangia are borne in interrupted lines on the margin of the leaflets, and are covered by a false indusium. Several ferns belonging to the genus *Polypodium* (*e. g.*, the common polypody and the licorice fern) have pinnate leaves growing singly from an elongated creeping rootstock. The sporangia are borne on the backs of the leaf lobes in round sori without an indusium. These ferns grow mostly in moss or decaying vegetable matter on rocks and tree trunks.

The stem structure described in *Pteridium* (the brake) is one of four kinds of structure found among the true ferns. All four kinds have a central cylinder of vascular tissue, called a stele, surrounded by a rather thick cortex of living cells. The four kinds of steles are as follows: (1) The protostele (*Gleichenia*, a tropical fern) in which there is a

central cylindrical strand of vascular tissue without pith, the xylem being inside and the phloem entirely surrounding it. This is regarded as an early form in the development, or evolution, of vascular stems. (2) The amphiphloic siphonostele (*Adiantum*, the common maidenhair), in which the stele is a tube with pith inside and an endodermis outside. The xylem in this stem is in the form of a tube with a layer of phloem inside of it and another outside. It is called a siphonostele because it is in the form of a siphon, or tube, and is called amphiphloic because the phloem is on both sides of the xylem. (3) The polystele (*Pteridium*) in which the stele consists of several separate bundles, each with a xylem in the center, without pith, and a phloem all around it, and an endodermis around this (Fig. 115). (4) The ectophloic siphonostele (*Osmunda*, the royal fern) in which the stele is a tube with pith in the center, and the xylem is in separate strands with pith rays between them and the phloem is outside of the xylem. This stele is called ectophloic because the phloem is outside of the xylem. It is regarded as the highest stage in the development or evolution of stems among the true ferns, and it is somewhat similar to the stems of seed plants.

Both the sporophyte and the gametophyte of the true ferns are reproduced vegetatively. In the brake new sporophytes arise by the continued growth of the branches of the rhizome and the decay of the older portions until the branches are separated. In some ferns buds are produced on the sporophyte, and these grow into new sporophytes. The gametophytes of some ferns produce bodies called gemmæ, which grow into new gametophytes in somewhat the same way that the gemmæ of the Bryophytes do. Instances have also been found in which the gametophyte produces a sporophyte vegetatively, and others where the sporophyte produces a gametophyte vegetatively, thus omitting from the usual life history the sex organs in the former case and the asexual spores in the latter. The former is called apogamy and the latter apospory.

THE TREE FERNS.

The tree ferns also belong to the order Filicales, and are closely related morphologically to the ferns of the family Polypodiaceæ, though they differ much from them in size and general appearance. The strength of their stems is due partly to the presence of large masses of sclerenchyma and partly to the growth of adventitious roots from the surface of the stem, forming a thick covering over it, often many times as thick as the original stem.

THE WATER FERNS.

The water ferns also belong to the class Filicales. The plants of two of the genera (*Azolla* and *Salvinia*) float, and consist mainly of leaves and roots. Those of the other genus (*Marsilea*) grow in the mud at the bottom of shallow water and send their leaflets up into the air. There are four leaflets on each stalk and they look somewhat like a four-leaf clover.

THE LYCOPODIALES.

Two genera of Lycopodiales are common—*Lycopodium* (club mosses) and *Selaginella* (moss ferns).

The Club Mosses.—The ground pine (*Lycopodium obscurum*) is a leafy plant with long creeping stems upon which are borne erect branching stems. The creeping stem may be either underground or on the surface, and in either case it is anchored to the soil by slender roots. The stems have a protostele, which in the mature plant has its xylem divided into irregular portions instead of being a solid mass as in the protostele of the true ferns. The metaxylem develops toward the center of the stem so that the protoxylem is on the outside.

Both the creeping stem and the erect ones are covered with small leaves borne in four ranks.

The spore-bearing structures are erect, club-shaped strobiles, borne in clusters of 2 to 4 on a slender, erect stalk arising from the end of a branch of the upright stem. The

strobile has a central axis, or stalk, completely covered with closely overlapping leaves, each of which has a sporangium on its upper surface at the base. A leaf which bears one or more sporangia is called a sporophyll, and the leaves of this strobile are all sporophylls. The sporangium of *Lycopodium* is developed from a row of cells which are covered by a layer of sterile cells. This is known as the eusporangiate method of sporangium formation, in distinction from the leptosporangiate method of most of the true ferns (*Pteridium*, p. 265).

The gametophyte is a tuberous subterranean body with a lobed, green, aërial crown in which the archegonia and the antheridia are borne. The sperms are biciliate, and in this they resemble those of the Bryophytes and differ from those of the true ferns. The archegonia are embedded in the tissue of the gametophyte, and in this way they resemble those of *Anthoceros*.

Other species of *Lycopodium* differ somewhat from the one described in form and general appearance and in the character of the sporophylls. The shining club moss (*L. lucidulum*) does not have a trailing stem, and the sporangia are borne in the axils of ordinary leaves of the erect stem. In this case the strobile, so far as general appearance is concerned, is not a specialized structure distinguished from the other portion of the branch, and the sporophylls are like the sterile leaves except that each bears a sporangium.

The Moss Ferns.—The moss ferns look somewhat like small club mosses. *Selaginella rupestris* is a grayish-green perennial plant found in many places in northern United States and in some places in the South. It forms mats on rocks in open places and has prostrate stems, sometimes 1 foot long, with erect branches usually less than 3 inches tall. The stem is covered with very small leaves, usually in eight ranks, and each leaf has a slender, whitish bristle at its tip. The sporangia are borne in erect, four-angled strobiles produced at the tips of the erect branches. They are on the stem, very close to the bases of the leaves. Some of the sporangia produce large spores called megaspores, and others produce small ones called microspores, the former producing female

gametophytes and the latter male gametophytes. The megasporangia are orange colored and are large enough to be seen with the unaided eye. A plant producing two kinds of asexual spores is called a heterosporous plant, and the condition is called heterospory. The moss ferns, being heterosporous, differ from the true ferns, which are all homosporous. Both kinds of gametophytes are small and are produced within the spore wall. A striking feature of the moss ferns is that the megaspore is not discharged from the sporangium. The development of the female gametophyte, the fertilization of the egg in the archegonium, and the beginning of the development of the sporophyte, all take place in the strobile, where the megaspore was formed. In being heterosporous and retaining the megaspore within the sporangium wall and forming the young sporophyte there, *Selaginella* shows close similarity to the seed plants. In the character of the male gametophyte this plant also shows features like those of the seed plants, but in having biciliate sperms it resembles the Bryophytes, and it also resembles some of the Bryophytes (*Anthoceros*) in having the archegonia embedded.

THE QUILLWORTS (ISOETALES).

The quillworts are perennial plants, usually growing under water. They are anchored to the substratum by numerous forked roots, and sometimes occur where the water is as much as 10 feet deep, though they are usually in much shallower water, and are sometimes found in places where the receding water leaves them exposed to the air during a part of the season. The plant looks somewhat like a tuft of grass or sedge a few inches tall. Its stem is so short and flat as to be somewhat disk-like, and is almost completely concealed by the flattened bases of the leaves, the upper portions of which are round and tapering. Each of the outer leaves bears a sporangium in a cavity in the inner surface of its base, partly covered by a membrane. Each sporangium is separated by partitions into several cavities in which the spores are borne. The sporangia are of two kinds—megasporangia, bearing megaspores, and microspor-

angia, bearing microspores. The sporophylls are also of two kinds, megasporophylls and microsporophylls. The gametophytes are of two kinds—female, produced by the megaspores, and male, produced by the microspores. Both are similar to those of *Selaginella,* but the sperms are multiciliate. The quillworts all belong to one genus (*Isoetes*), which is the only genus of the family Isoetaceæ, and this is the only family of the order Isoetales.

THE HORSETAILS (EQUISETALES).

The horsetails (Fig. 124) are jointed plants with longitudinally ribbed stems, which feel rough to the touch, and inconspicuous leaves united in a whorl at the nodes. They all belong to the genus *Equisetum* and this is the only genus in the order Equisetales.

The field horsetail (*E. arvense*) is common in many parts of the United States and other countries. It grows in meadows and cultivated fields, and is especially common on railroad embankments. It is quite variable in form and appearance, but certain features are always present. It has two kinds of stems, fertile and sterile, both growing from the same perennial rhizome, which is sometimes as much as 1 foot underground. Both kinds of stems are hollow.

The fertile stems are light brown in color, are unbranched, and usually less than 1 foot tall. They come up early in the spring, grow rapidly, and die as soon as they have shed their spores. The sheath of leaves is whitish, and ends in about 12 slender, tapering teeth. Each stem bears at its tip an erect slender cone-like strobile. When the strobile is young its surface is formed by six-sided disks crowded closely together, but as it becomes older these disks separate, and each is seen to be borne on a stalk and to have several sporangia projecting inward from its inner surface. Each disk with its stalk is thus morphologically a sporophyll. Each sporangium opens by a slit and discharges its spores.

The sterile stems (Fig. 152) are green and branched, and are usually taller than the fertile ones, though they sometimes have a spreading form. They appear about the time that the fertile ones are shedding their spores, continue

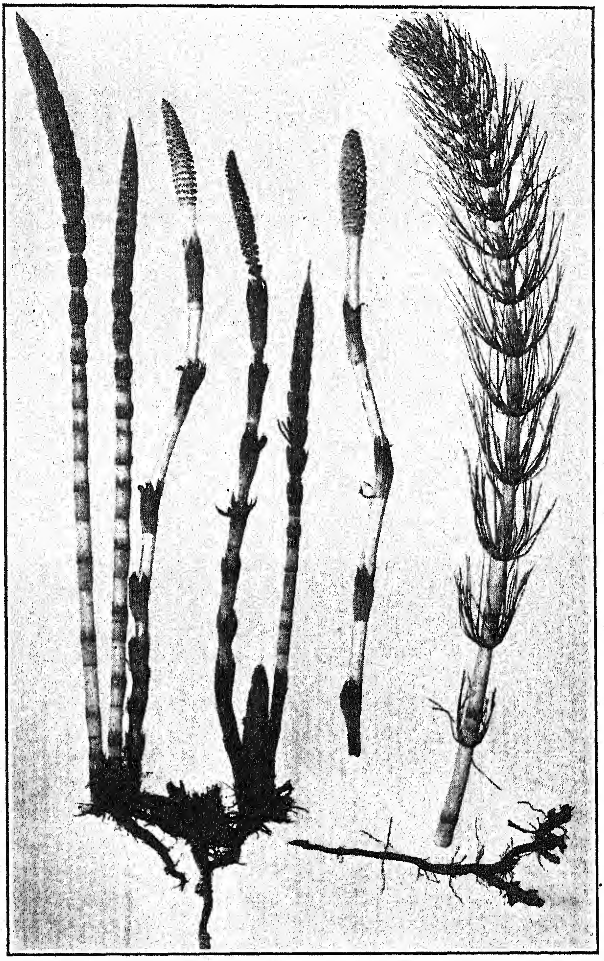

FIG. 124.—A scouring rush (*Equisetum telmateia*). Left, a rhizome with three sterile stalks, and two fertile stalks, each bearing a strobile at the top. Center, a stalk bearing a strobile and showing whorls of united leaves. Right, an older sterile stalk, showing whorls of branches. Lower right, portion of a rhizome with roots.

growing during the summer, storing up food in the underground rhizome, which is used by the non-chlorophyll-bearing fertile stem in its growth, and die in autumn. Tuber-like bodies, which probably store food, are found on the rhizome. The sterile stem has 6 to 9 ribs, and its branches are sharply three- or four-angled. It contains much silica in its epidermis and has stomates.

The spores are numerous and are pale green in color. Each one has two strap-shaped appendages attached at their middle to one pole of the spore, thus forming four free portions which coil tightly around the spore when wet and spread out when dry. These appendages are called elaters, and their movements are readily seen under the microscope if the spores are mounted on a slide without a cover-glass. When they are breathed on the elaters coil up and then uncoil as they dry. These spores all look alike, but they produce two kinds of gametophytes, male and female, and the entangling of the spores in a mass because of the action of the elaters makes probable the presence of both sexes in the group of gametophytes, so that fertilization is relatively certain. The gametophytes are small, branched structures and are not commonly seen.

The giant horsetail (*E. telmateia*) (Fig. 124) occurs in western United States and in Europe. It is very similar to the field horsetail, and shows the general features of the genus *Equisetum*. It is, however, much larger than the field horsetail, its sterile stems sometimes reaching a height of 6 feet, and it is less variable in form. Some species of *Equisetum* are evergreen. An example of these is the common scouring rush (*E. hyemale*), which is found in many parts of the United States but not in the extreme south. Its stems are from 2 to 4 feet tall and seldom branch. They are very rough and were formerly used for scouring floors.

In their vascular anatomy the stems of *Equisetum* differ considerably from those of the other Pteridophytes. There is one vascular bundle in each ridge of the stem, but the bundles are poorly developed, the xylem being largely replaced by an air passage. The xylem and the phloem lie side by side and the bundles are, therefore, collateral. The metaxylem develops outwardly from the protoxylem. This

is regarded as a high character, since it is the condition found in seed plants. The stomates are in the furrows between the ridges, and chlorophyll is most abundant in the cells near them. The work of photosynthesis is done by the stem, and not by the leaves.

THE GRAPE FERNS.

The Ophioglossales are illustrated by the common grape ferns (several species of *Botrychium*). The stem is entirely underground and the leaves are fleshy. One portion of the leaf is vegetative and the other produces the globular clustered sporangia. The vascular cylinder is a siphonostele made up of collateral bundles, each containing cambium, and thus having secondary growth. The bundles are separated by pith rays, and the whole stele is strikingly like that of the seed plants.

LINES OF DEVELOPMENT.

The Pteridophytes are clearly distinguished from the Bryophytes by the character of the sporophyte. The sporophytes of the Pteridophytes have leaves, stems, and roots, all of these organs having vascular tissue, and, after a brief connection with the gametophyte, they become independent. They are thus quite different from even the most highly developed sporophytes found among the Bryophytes. The Pteridophytes are distinguished from the Spermatophytes (seed plants) by the fact that they do not have seeds.

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CHAPTER XVIII.

THE CONIFERS AND THEIR CLOSE RELATIVES (GYMNOSPERMS).

THERE are four groups of living gymnosperms—the Cycadales (cycads), the Ginkgoales (the maidenhair tree), the Coniferales (the yews and the pines and other conifers), and the Gnetales (*Ephedra, Tumboa,* and *Gnetum*). There are also some extinct gymnosperms whose fossil remains give some clues to the development of the group.

The conifers are the Gymnosperms most commonly seen in the north temperate zone, and they furnish the natural point of beginning in describing the class. Since the pines are widely distributed and are fairly representative of the conifers, an understanding of the group may be given by describing these and then comparing some others with them.

THE PINES.

The pines are cone-bearing, evergreen trees whose leaves are borne in clusters (fascicles) of two, three, or five. Their stems (Fig. 31) have pith, wood, cambium, and bark. The pith is undifferentiated tissue, consisting of living cells in very young stems, but of dead cells with lignified walls in the older ones. In the large trunk of the tree the pith is insignificant in amount. Just outside the pith is the protoxylem and outside of this is the metaxylem, the two constituting the primary xylem, showing no regular arrangement of its cells. The metaxylem develops outside of the protoxylem. Outside the primary xylem is the secondary xylem, which makes up the main portion of the wood of the tree. It shows annual rings and wood rays. Each annual ring consists of two portions—the spring cells and the summer cells. The spring cells have thin walls and large lumen,

while the summer cells have thick walls and relatively small lumen. The wood rays are bands of short cells radiating from the center with some short tracheids accompanying them. The living cells of the rays in the wood have large nuclei, and many of them, at least in winter, contain starch grains. The primary wood rays extend outward from the primary xylem, and since this is small in amount they often seem to extend from the pith, and hence are often called pith rays. The rays are formed from the cambium and the secondary rays formed later may be traced inward from it, but do not extend all the way to the primary wood. The wood ray of the pines is a flat structure, usually one cell in thickness and six to eight or more cells in height, occupying a radial position in the stem. The xylem contains no true parenchyma, and is made up largely of elongated tapering conductive cells called tracheids, whose walls have bordered pits (Fig. 35) which are common to the walls of two tracheids where they are in contact. Resin canals extend crosswise of the stem in some of the wood rays, a ray containing a resin canal being several cells thick.

The cambium lies between the wood and the bark and consists of a few layers of cells somewhat rectangular in cross-section arranged side by side in rows. These cells have thin walls, large nuclei, and active protoplasm. Cambium is a meristematic tissue, and as its cells divide some of the cells produced remain meristematic, some form xylem (wood) on the inner side of the cambium, and others form phloem (bark) on the outer side.

The bark contains sieve cells, phloem rays, bast, stone cells, crystal cells (Fig. 28), and parenchyma, and when very young is covered with an epidermis which is later replaced by a layer of cork several cells thick. The sieve cells are elongated, with tapering ends, and are mostly rectangular in cross-section. During its functional period a sieve cell contains protoplasm, which is continuous with that of others in contact with it through pores in the sieve plates in its side walls. As the sieve cells become older, the protoplasm disappears, and each sieve plate is covered by a callus which closes the pores. The sieve cells usually function during

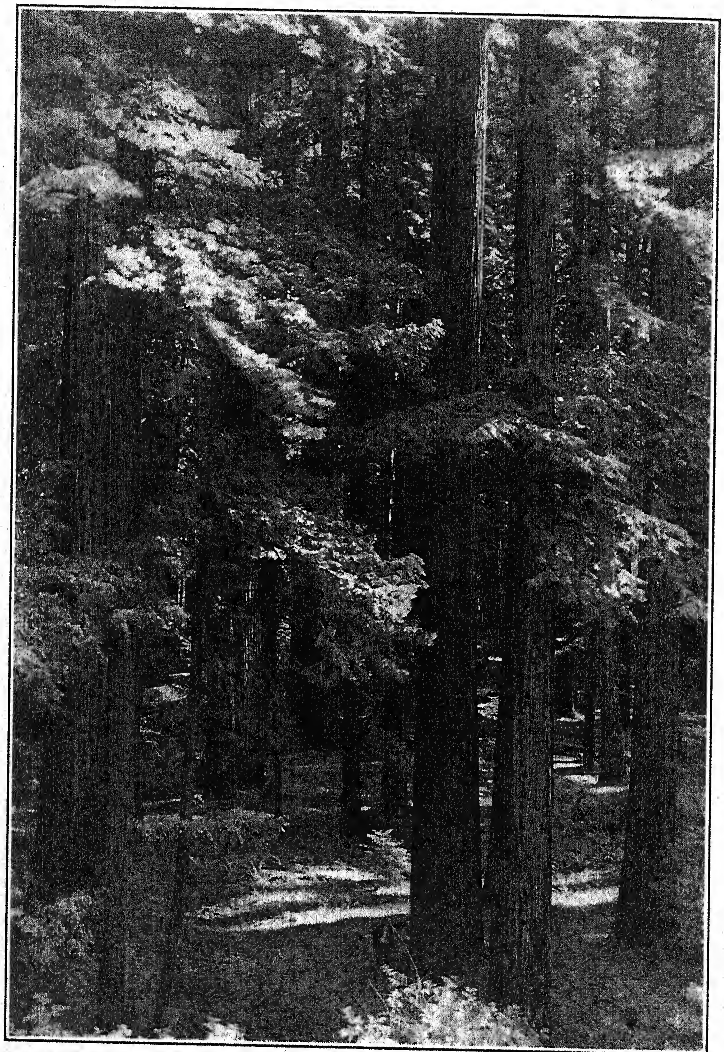

FIG. 125.—A redwood forest on Bull Creek flat near Dyeville, Calif. (Courtesy of W. G. Corbitt.)

their first year only, and in the portion of the bark more than one year old they are usually collapsed.

The phloem rays extend outward from the cambium, and many of them seem continuous with those of the rays in the wood. The rays are straight in the newer portion of the bark, where the sieve cells retain their protoplasm and are still active, but become irregularly curved farther out, where the sieve cells are dead and collapsed. Some of the ray cells have communication with the sieve cells through pits in the walls of both.

Parenchyma is not abundant in the phloem portion of the bark, though it may occur farther out in young bark as cortical parenchyma. In the phloem portion it is composed mostly of scattered rows of cells extending lengthwise of the stem. In the younger portions of the bark these cells are living and have large nuclei, and contain starch grains at least during the winter. Resin canals extend lengthwise in the cortical parenchyma of young bark.

The cells of the protective layer of cork which covers the bark of the older stems of the pines are rectangular in cross-section and lie side by side in radial rows. When mature they are dead cells and show only walls and lumen. Their walls are composed largely of a fatty substance called suberin, which is practically impervious to moisture, and thus protects the deeper lying tissues from the loss of water by evaporation. Patches of looser tissue called lenticels are common on the twigs and younger stems, and allow the exchange of gases by diffusion between the tissues of the bark and the outer air. Cork is formed from meristematic tissue called cork cambium (phellogen) which originates from cells in the outer portion of the bark, and the tissue of the lenticels is also formed from this cambium. As the bark grows older, new layers of phellogen are formed farther in, and the outer portions of the bark thus cut off are eventually shed as small scaly masses.

The wood of a pine stem is thus seen to be composed of xylem, while the phloem forms a considerable portion of the bark. In the mature stem the vascular bundles do not appear as separate structures, but when they are first formed

from the apical meristem in the elongating tip of the stem they can be recognized as individuals. They are collateral, since the xylem and the phloem lie radially side by side, and they have cambium and are thus capable of secondary thickening.

The roots of the pines when they are several years old are similar in structure to the stems except that they have no pith, the central portion being occupied by the primary wood. The amount of primary wood is relatively large, and the metaxylem develops inward from the protoxylem. The root is thus exarch while the stem is endarch. Cortex is present in the young root (Fig. 44), but it does not increase much and soon disappears as the root grows. Hairs are present on the young root, but they are not abundant and do not last long.

The leaves of some species of pine are very long (over 6 inches), while those of others are much shorter. They are all needle-like, and have an epidermis (Fig. 15) composed of one layer of thick-walled cells, beneath which is a hypodermis, composed of one or more layers of cells whose walls are also thick. The stomates are sunken in the epidermis. A single vein composed of one or two vascular bundles extends lengthwise through the center of the leaf. Outside the bundles is a layer several cells thick composed partly of parenchyma and partly of transfusion tissue (Fig. 15) whose cells are empty and whose walls are pitted. Outside of this is an endodermis of one layer of cells, and between the endodermis and hypodermis is the mesophyll. The cells of the mesophyll contain chloroplasts, and the walls of the cells are infolded so that they project into the interior of the cell. Several resin canals extend lengthwise through the mesophyll.

The strobiles of the pines are of two kinds, ovulate and staminate. The ovulate strobile is woody and is what we call the cone of these trees. These cones remain on the tree more than one year, falling at the end of the year in which the seeds are mature (usually the second season) in many of the species, but persisting for many years in a few. The cone has a central axis on which the scales are borne. In the mature cones the scales are large and usually woody.

On the inner surface of each scale of the young cone are borne two ovules, each with its micropyle opening toward the base of the scale. The scale is the megasporophyll, the ovule is the megasporangium, and the megaspore is commonly called the embryo sac. The micropyle is the opening in the integument of the ovule, the main body of the ovule is the nucellus, and the embryo sac is borne within this.

The staminate strobiles are borne in clusters around young twigs and are smaller and more numerous than the ovulate ones. They are temporary structures, withering as soon as the pollen grains are discharged. Each has an axis on which are borne bract-like microsporophylls, each of which has a sterile tip and bears two pollen sacs (microsporangia). The pollen grains (microspores) are formed in tetrads from the pollen mother cells. The grains are produced in large numbers, and each has two rounded, wing-like, membranaceous extensions of the outer wall which facilitate its transfer by wind.

The megaspore germinates and produces within the nucellus the female gametophyte, which consists of a large mass of nutritive tissue and a few archegonia. The nutritive tissue is called the endosperm, and it represents the vegetative portion of the female prothallus. The neck of an archegonium is several cells thick, and a ventral canal is formed which disintegrates, opening a passage to the egg in the venter.

The scales spread at the time of pollination so that a quantity of pollen collects at the base of the scale and some of the grains come into contact with the micropyle. The lips of the integuments roll up and unroll with changes in moisture, and some of the pollen grains are thus pressed against the surface of the nucellus.

The pollen grain (microspore) produces the male gametophyte. The grain undergoes divisions before it is shed from the microsporangium, and produces four cells within its wall. Two of these cells are vegetative and are thought of as representing the vegetative portion of a prothallus. Both of these disorganize after the other two (generative cell and tube nucleus) are produced. The pollen grain when shed is thus a two-celled structure which may be thought of as an

antheridium. The further growth of the pollen grain takes place after it enters the micropyle of the ovule and comes into contact with the nucellus. The generative cell divides, producing two cells, and the pollen tube grows from the cell containing the tube nucleus. This tube penetrates the tissue of the nucellus and reaches the neck of an archegonium. The tube nucleus and generative antheridial cell pass into the pollen tube, and by division the latter produces two cells, one of which divides to form two male nuclei. One of the male nuclei enters the archegonium and fertilizes the egg, producing the oöspore from which the embryo of the sporophyte grows. The male cell is not ciliated, and its transfer to the archegonium is provided for by the pollen tube. Only one seed is produced in an embryo sac, though there are several archegonia.

The seed of the pines consists of the embryo and the endosperm, both enclosed within a seed coat (testa) derived from the integument of the ovule. Each seed has a wing derived from the tissue of the scale. The embryo is embedded in the endosperm, and consists of root tissue, a hypocotyl (stalk), and several cotyledons (seed leaves). Though the seed is essentially a young sporophyte, it must be remembered that its endosperm is derived from the female gametophyte. Two years or more elapse between the reception of the pollen grain and the maturity of the seed. The seed is a resting stage of the sporophyte, and when it germinates it produces the tree.

SOME OTHER CONIFERS.

While the pines are representative of the Coniferales, other trees of the group differ from them in certain particulars, among which are the size and character of the ovulate cones; the length of time required for the maturity of the seeds; the character, arrangement, and duration of the leaves; and the character of the bark.

The Douglas fir (*Pseudotsuga taxifolia*) (Frontispiece) is a large coniferous tree of western United States and Canada. It is the dominant tree of much of the forest in northwestern

United States and southern British Columbia. The bark on the twigs and young stems has blisters containing pitch, but on the older stems these disappear and on large trees the bark is very thick and has deep longitudinal fissures. The wood is somewhat pitchy and is very hard. It is a valuable wood, much used for lumber. The heart wood is reddish, but the sap wood is lighter in color. Its leaves are borne singly and are spirally arranged (Fig. 126). They are usually about 1 inch long, and are flattened, the width being about $\frac{1}{16}$ inch.

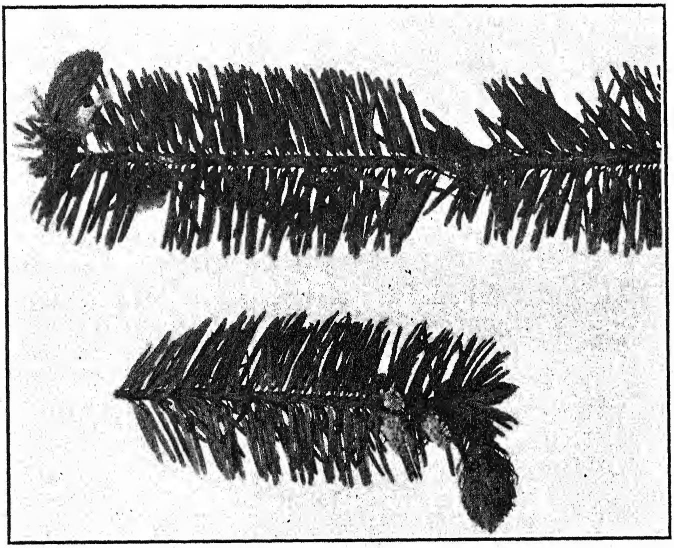

FIG. 126.—Twigs of Douglas fir with young cones (strobiles). Upper, a young ovulate strobile erect at the tip of the twig. Lower, an ovulate strobile turned down after fertilization. Staminate strobiles near the ovulate one. The leaves are evergreen and needle shaped.

The ovulate cones (Fig. 126) are produced near the ends of the twigs, usually one on a twig, and when young they are erect, and the red color of many of them makes them conspicuous and attractive objects in the spring. After fertilization takes place the cone turns down and later becomes

woody. The mature cone (Fig. 130) is readily distinguished from that of many other conifers by the three-pointed bracts which are longer than the scales. The seeds mature during the same season that the cones are formed, and the cones usually fall in autumn.

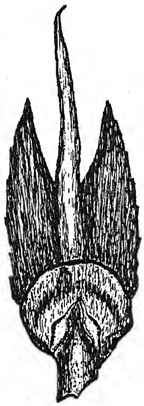

FIG. 127.—A scale and bract of Douglas fir. The inner face of the scale is shown, with the two ovules. The bract is the three-pointed structure, which at this stage is much larger than the scale. (Drawn by E. T. Bodenberg.)

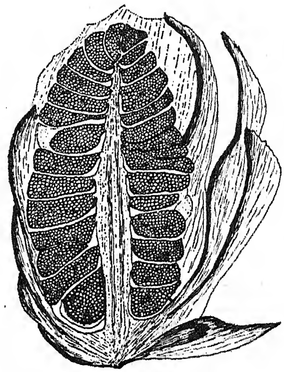

FIG. 128.—Longitudinal section of staminate strobile of Douglas fir with involucral bracts. The strobile consists of the central stalk and the pollen sacs. (Drawn by E. T. Bodenberg.)

The staminate strobiles (Fig. 126) are small and are borne singly in the axils of the leaves of the same twigs on which the ovulate strobiles are borne. They are numerous and often occur on twigs on which there are no ovulate strobiles. The buds (Fig. 126) are scaly, and the three kinds (stem buds ovulate strobile buds, and staminate strobile buds) are much alike in general appearance. There are both terminal and lateral stem buds, but the terminal ones are much more vigorous in their growth and the strong development of the terminal bud of the main stem gives the tree its huge straight trunk. The strobile buds are always lateral, though the ones producing ovulate strobiles are very close to the tip of the twig.

The redwood and the big tree of California both belong to the genus *Sequoia*. They are gigantic in size, reaching a height of 350 feet or more, and some of them are known to be at least four thousand years old. Their origin is ancient. Remains show that they existed in the Arctic zone in the cretaceous and tertiary periods. Their wood is light in weight and reddish-brown in color. It is of excellent quality and very durable in all kinds of exposure, lasting for years without decay, and is widely used for commercial purposes. The bark is remarkably thick, sometimes as much as 18 inches. Both of these trees are evergreen, the leaves remaining on the branches three or four years.

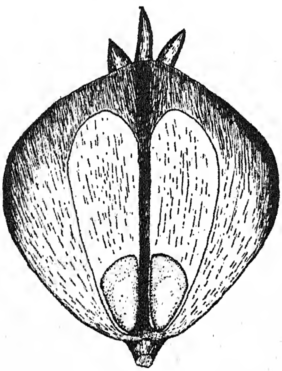

FIG. 129.—Inner surface of scale of mature Douglas fir cone, showing the two seeds, each with a wing, and the three-pointed bract projecting above the scale. (Drawn by E. T. Bodenberg.)

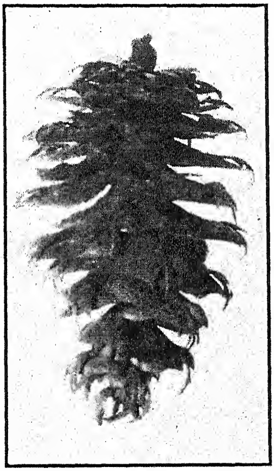

FIG. 130.—An old cone of Douglas fir that has discharged its seeds.

The "flowers" (staminate and ovulate strobiles) are small and inconspicuous, and the two kinds are borne on different branches of the same tree. The mature cones are egg-shaped and are from 1 to $3\frac{1}{2}$ inches long. The scales of the cone are thick, woody, and closely crowded, and each scale bears from 5 to 7 small seeds. Squirrels cut down and bury

many cones, and the seeds germinate under favorable conditions and produce good seedlings.

The big tree (*Sequoia gigantea*) is a mountain tree occurring on the west side of the Sierras, generally at elevations of 5000 to 8500 feet. It is not very tolerant of shade. It is ordinarily 250 to 280 feet tall, with a diameter of 12 to 17 feet, and ages from eighteen hundred to twenty-five hundred years are common. Its trunks are conspicuously buttressed at the base. The redwood (*Sequoia sempervirens*) is confined to humid regions subject to frequent, heavy fogs, and occurs in the coastal regions of California, reaching its best development (Fig. 125) on protected flats, benches, and river deltas and on west slopes and in valleys opening toward the sea. It is reproduced abundantly by sprouts from old or young stumps.

The genus *Abies* comprises the balsam fir and the true firs. The former is a slender tree found in northern and northeastern United States, and the latter (white fir, Shasta fir, noble fir, and others) are large trees abundant in northwestern United States and in British Columbia. The wood is white and soft, and the bark is thinner than that of the Douglas fir. The young bark has superficial blisters which contain pitch. They usually have flattened leaves slightly notched at the end, originating spirally but growing out at the sides of the horizontal branches, giving the branches a decidedly flat appearance. The mature cones are erect and do not fall, the seeds being freed by the shedding of the scales. The seeds mature during the same year that the cones are formed.

The spruces (*Picea*) are found in many parts of the United States, Canada, and other countries. They are mostly large trees with whitish wood which is not very pitchy, though resin ducts are present. Their cones have thin scales and are pendulous, and mature the first year. Their leaves are needle-shaped, usually sharp at the tip, square in cross-section, and are spirally arranged.

The hemlocks (*Tsuga*) are common in the coniferous forests of the United States, Canada, and other countries. The leaves, though spiral, appear two-ranked and give the

branches a flattish appearance. They are whitish on the lower surface. The cones are small and pendulous on short leafy branches.

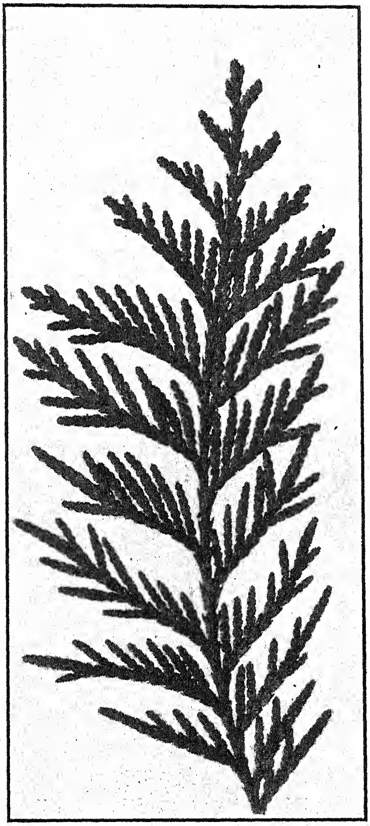

FIG. 131.—A twig of the giant cedar (*Thuja plicata*) with evergreen, scale-like leaves.

The genus *Thuja* includes the white cedar of northern and eastern United States, and the red cedar of western United States. The wood is durable in all kinds of exposure and is

used for shingles. Both are found also in Canada. The red cedar (Fig. 131) has flat, scale-like, green leaves closely appressed to the branches. Its wood is soft and red. Its bark is fibrous and may be pulled from the tree in long pieces. Its cones are small and tend to grow erect.

The junipers (*Juniperus*) are trees and shrubs, some of which have two kinds of leaves, awl-shaped and scale-like. Some of the shrubs are prostrate. The "fruit" is a bluish berry whose flesh is formed by the union of the cone scales which thus enclose the seeds.

The tamaracks, or larches (*Larix*), are forest trees with deciduous leaves borne in clusters of more than five on very short knob-like branches.

The yews (*Taxus*) belong to the family Taxaceæ, while all of the conifers described above belong to the Pinaceæ. They do not have cones, and the "fruit" consists of a single bony seed surrounded by a fleshy ring (morphologically the scale) which is red in some species but purple or green in others. The "flowers" are solitary and axillary, not in strobiles. The leaves are flat and project from the horizontal branches in two rows, though they originate spirally. Their wood is red and is very hard.

THE CYCADS.

The cycads (Cycadales) are tropical plants, somewhat fern-like in appearance, with large, pinnately-branched leaves. The stems are all tuberous when young and are subterranean in some species, though in a few they grow to a height of 50 feet or more. The pith of the stem is large, the cortex is thick, and the vascular cylinder is thin. Cambium is present in the young stems, but there is very little secondary growth, and new bundles are sometimes formed in the cortex so that new vascular cylinders are formed outside of the original one. The vascular bundles are collateral and endarch, like those of other gymnosperms.

The ovulate and staminate cones are borne on different plants, and in this way they are different from the pine

family. There is usually one strobile at the tip of the stem and it is apparently terminal. It is really lateral, however, and sometimes there is more than one. The strobiles are usually much larger in proportion to the size of the plant than they are in the Coniferales, the ovulate ones being especially large in some species. There is a pollen tube, but it functions in absorption rather than in providing a passage for the sperms to the archegonium, for the sperms are ciliated and swim in a cavity in the nucellus. In having a pollen tube the cycads resemble the other gymnosperms, but in having ciliated sperms they resemble the Pteridophytes. One vegetative cell persists in the pollen grain at the time that it is shed, and in this also it differs from that of the pines. The cycads have exposed seeds, and, therefore, are gymnosperms. Cycads are found as fossils, and were more abundant in mesozoic times than they are at present.

THE MAIDENHAIR TREE.

The Ginkgoales are represented by only one species, the maidenhair tree (*Ginkgo biloba*). It is a small tree growing wild in some parts of China and in cultivation in other parts of China and in Japan and the United States. The stem has wood, pith, and bark, the wood being thick and the pith small. It has broad, wedge-shaped, two-lobed, deciduous leaves with forked veins. The sperms are multiciliate. The seeds are naked, but the outer seed coat is fleshy so that the mature seed resembles a plum in size and general appearance.

THE GNETALES.

The Gnetales are placed highest in the sequence of the groups of Gymnosperms because they bear the most striking resemblances to the Angiosperms. There are three genera, and each genus differs a good deal from the others in the form of the plants. *Ephedra* has several species in the warm dry regions of southwestern United States and in similar

places in some other countries. They are shrubby green plants with irregularly spreading branches and opposite leaves which are mere scales. *Tumboa* is found in South Africa, and has a short, thick, woody stem and one pair of long, parallel-veined leaves whose bases continue to grow year after year while the ends die. The several species of *Gnetum* are small tropical trees or woody vines, having opposite, netted-veined leaves.

The Gnetales are somewhat intermediate between the Gymnosperms and the Angiosperms. Among their gymnosperm characters are strobiles and naked seeds. Among their angiosperm characters are opposite leaves, some of which are parallel-veined and some netted-veined; the absence of archegonia in many of the species; the presence of a sort of perianth in the flowers; and the presence of vessels in the secondary wood.

EXTINCT GYMNOSPERMS.

Three groups of gymnosperms which do not now occur as living plants and are known only from their fossil remains contribute a good deal to our understanding of the evolution of plants. The Cycadofilices flourished in the latter part of the Paleozoic era, especially in the Carboniferous period. They were fern-like in appearance and somewhat in stem structure and other characters, but they had secondary wood and they produced seeds. The discovery of these fossil plants and the working out of the essential points in their life history has done much to bridge the large gap that exists between the living Pteridophytes and the living Gymnosperms. The Cordaitales were tall trees flourishing in the Paleozoic era with the Cycadofilices, and were perhaps the dominant forest trees of the time. They show relationships with both the Cycadofilices and the living gymnosperms. The Bennettitales flourished during the Mesozoic era and their remains are so much like the Cycads that they are often called fossil cycads, though they differ from the living cycads in certain essential points.

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CHAPTER XIX.

THE GENERAL CHARACTER OF THE ANGIOSPERMS.

THE angiosperms are plants whose seeds are enclosed within a structure called an ovary, and are thus distinguished from the gymnosperms, in which the seeds are naked on the inner face of a scale. Seeds develop from ovules, and in the angiosperms the ovules are enclosed within the ovary, while in gymnosperms the ovules are naked on the face of the scale. All of the angiosperms have flowers, though in some of them, such as the cat-tails and the grasses, the flowers are not what we commonly think of as flowers, and their parts are recognized only by careful examination.

The flower has been described in Chapter V, but some further details of the stamens and the carpels are necessary in order to understand the relationship of the angiosperms to the other groups. The stamen is a microsporophyll, the anther consists of microsporangia, and the pollen grains are microspores. In the development of an anther four masses of spores are formed, but these frequently fuse into two, so that the mature anther consists of two sporangia (pollen sacs). The pollen grain undergoes division before it leaves the anther, usually producing a generative cell and a tube nucleus, and there are thus two nuclei present in the dormant pollen grain. The pollen grain has two coats, the outer one being much harder than the inner one. When the grain lodges on the stigma the outer coat is burst as germination takes place and the pollen tube is produced. The generative cell divides, producing two male nuclei which pass down the tube and function as gametes in the fertilization which follows.

In most cases no nütritive cells are produced in angio-

sperm pollen grains, and the development of the pollen grain thus differs from that seen in the gymnosperms where so-called nutritive cells are produced though they contain but little food and soon disappear. The angiosperm male gametophyte consists of an antheridium only and is thus the simplest gametophyte found.

The carpel is a megasporophyll, the ovule is a megasporangium, and the cell that forms the embryo sac is the megaspore. There are usually four megaspores formed, only one of which develops.

The ovule (Fig. 53) is borne on a short stalk called the funiculus and has a basal portion, the chalaza, which consists of meristematic tissue from which the nucellus and the integuments develop. The nucellus is the main body of the ovule and is enclosed within one or two integuments, having an opening called the micropyle. The embryo sac is contained within the nucellus. The development of the embryo sac consists in successive divisions of the megaspore nucleus by which 8 nuclei are produced. Three of these, called the antipodals, are situated at the end of the embryo sac opposite the micropyle; 3, the egg and the 2 synergids (co-workers), are in the region near the micropyle; and 2, called the polar nuclei, occupy the central position where they unite, forming the fusion nucleus. The antipodals do not function in fertilization. They are sometimes enclosed in delicate walls, and it is thought by some that they may possibly represent a prothallus.

The pollen tube, having grown down through the style frequently along a canal, reaches the nucellus either through the micropyle or by penetrating the integuments and grows through the tissue of the nucellus, finally penetrating the wall of the embryo sac. One of the male nuclei fuses with the egg, forming the zygote from which the embryo grows, while the other unites with the fusion nucleus, and from this union the endosperm is produced. This constitutes the double fertilization which is characteristic of all angiosperms and has not been found in any gymnosperm. This double fertilization was discovered in 1898.

The structure of leaves, stems, roots, and seeds has already

been described (Chapters II, III, and IV). The details of the structure of these organs which are of morphological significance are best brought out in the discussion of the two subclasses, the Monocots and the Dicots.

These two subclasses are separated on the basis of characters of the flowers, seeds, leaves, and stems. The monocot flower usually has the parts of each circle in three's or six's, never in five's, while the dicot flower usually has its parts in four's or five's, though in some cases in one's or two's. The seeds of monocots have only one cotyledon, and the first leaves of the young plant are always alternate, while the seeds of dicots have two cotyledons borne opposite each other, and the first two leaves of the young plant are opposite in many of the common species.

The leaves of the monocots are usually parallel-veined, while those of the dicots are netted-veined. A few monocots, however, such as the green brier (*Smilax*) and some of the Araceæ (*e. g.*, skunk cabbage) have netted-veined leaves. Some of the dicots, such as the elm trees (*Ulmus*), have their main veins parallel, but have small netted veins between these. The stems of the monocots have the vascular bundles scattered through the parenchyma and thus have no clear differentiation of pith, while the dicots either have their bundles combined so as to form bark and wood with pith in the center or, if their bundles are separate, they are arranged in a circle with the pith in the central part of the stem. The bundles of monocots have no cambium, hence are incapable of secondary growth even if the stem is perennial, while the bundles of the dicots have cambium and are capable of secondary growth which in perennial stems results in annual rings. *Aloe*, a few palms, and some other monocots are exceptions to this, but their secondary growth is of a rather special character.

While the monocots and the dicots are thus distinguished by four sets of characters, it is not easy to take any one of them as an unfailing means of separating the two subclasses, and combinations of the characters must usually be sought.

CHAPTER XX.

THE MONOCOTS.

THERE are in the world 45 families of monocots, and it would be impossible within the scope of this book to describe all of them or even all of those (more than 20) found in the United States. A general idea of this group can be given, however, by discussing in morphological sequence the lowest family of the group, 5 intermediate ones, and the highest. Families are grouped into orders, and if all of the families were to be discussed it would be well to discuss the 11 orders (*e. g.*, Graminales, Liliales, and Orchidales, etc.) into which they are grouped, but in a brief treatment the main lines of relationship may be indicated by describing the 7 families indicated without discussing the orders.

THE CAT-TAIL FAMILY.

The Typhaceæ (cat-tail family) are herbs growing in marshes or in shallow water from either perennial rhizomes or perennial roots. Their leaves are linear and have no petioles. The stem is sheathed by the bases of the leaves, and its upper portion shows no nodes.

The flowers are imperfect and have no true perianth. The cat-tail flag (*Typha*) is the common representative of this family in the United States and many other north temperate regions. Its pistillate flowers are borne all around the stem, and form a dense cylinder 1 inch or more in diameter and 6 inches or more in length, which is brown when the fruits are mature, while the staminate flowers form a smaller cylinder of about equal length above them, extending practically to the tip of the stem. The staminate ones wither after their pollen is discharged, but the fruits produced by the pistillate ones persist until winter, forming together with

the dense growth of long hairs on them the familiar "cat-tail." Each pistil is borne on a short hairy stalk, and the ovary is one-celled and one-seeded. Pollination is by wind, and the pollen is extremely abundant. The monocot character of this plant is not so evident from the flowers, but is obvious from the scattered bundles of the stem and from the parallel-veined leaves.

THE GRASS FAMILY.

The Gramineæ (grass family) are mostly herbs with hollow stems closed at the nodes. The family includes the common grasses, such as timothy (*Phleum*) and blue grass, and the cereals, such as wheat (*Triticum*), oats (*Avena*), and corn (*Zea*), the latter one being an exception to the hollow stems. The leaf consists of a sheath which surrounds a portion of the stem, and a blade, with a membranaceous appendage at the junction of the two, called a ligule. The flowers (Fig. 135) are usually perfect, consisting of one pistil and commonly three stamens. The floret (flower) is enclosed in two bracts, the lower one called the the lemma and the upper one the palet. The ovary has one cell and one ovule, and there are commonly 2 styles, the stigma being covered with fine hairs. The anthers are fixed to the stamen by their middle (versatile) so that the ends swing freely. The grasses are wind-pollinated. The fruit, commonly called the seed, is a caryopsis (Fig. 135), consisting of a single seed closely covered by the seed coat and the ovary wall. The endosperm is large and its cells contain numerous starch grains, while the embryo is small. The monocot character of the plants of this family is evident from the one cotyledon and the parallel-veined leaves, and usually also from the scattered bundles.

THE PALM FAMILY.

The Palmæ (palm family) include the date palm (*Phœnix*), the coconut palm (*Cocos*), and the fan palm (*Borassus*), and are the only monocot family consisting mainly of trees. In fact, only one other monocot family (the Liliaceæ) contains any trees at all and it has only a few. The base of

each leaf in the Palmæ is a sheath, and the young flower clusters are enclosed in these sheaths. The flowers have a perianth but both circles of it are alike, and there is no true distinction between calyx and corolla. The number of parts in each circle of the flower is usually indefinite, though in some species it is three, and the three carpels are united into a single pistil. Some of the species are pollinated by wind and some by insects.

THE ARUM FAMILY.

The Araceæ (arum family) are mostly tropical, but are represented in the United States by the Indian turnip, also called Jack-in-the-pulpit (*Arisœma*), the skunk cabbages (*Symplocarpus* and *Lysichiton*) (Fig. 133), and the sweet flag (*Acorus*), which grow wild, and by the calla lily (*Richardia*) in cultivation. The flowers are small and are crowded on a fleshy body, called a spadix, which is usually surrounded by a large bract called the spathe. Some of the species have perfect flowers, others imperfect ones, and the flowers of some species have a perianth, while those of others do not. When the perianth is present it consists of from 4 to 6 parts, none of which are corolla-like. The fruit of most of the species is a berry.

THE LILY FAMILY.

The Liliaceæ (lily family) show the monocot characters plainly, and are usually considered to be the most representative monocots. They are mostly herbs, though a few are woody and the gigantic dragon tree (*Dracæna*) found in some tropical regions belongs to this family. A famous specimen of this tree which was blown down in 1808 was 70 feet high and 45 feet in girth and was supposed to be six thousand years old. Among the many common plants of the lily family growing wild in the United States are the lilies (*Lilium*), the dog-tooth violets (*Erythronium*), and the various species of the genus *Trillium*.

All of the members of this family have perfect flowers, and all the parts of the flower are borne on the receptacle

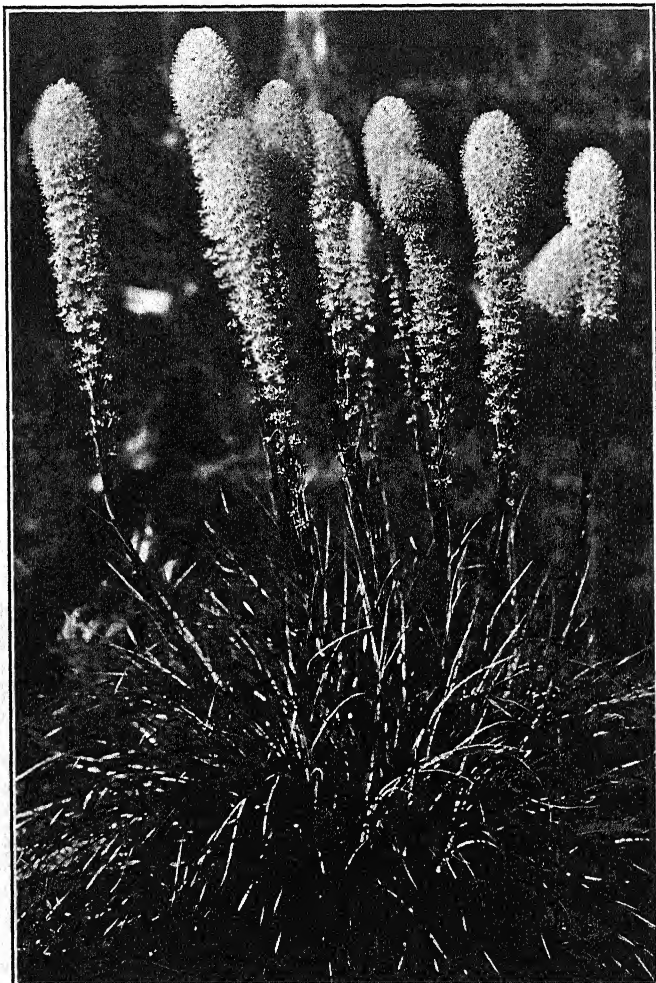

FIG. 132.—Basket grass (*Xerophyllum tenax*).

FIG. 133.—Western skunk cabbage (*Lysichiton camtschatcense*).

(hypogynous). All the parts of the flower are in three's or six's. The 6 parts of the perianth may be all alike, as in the Easter lily (*Lilium*), shown in Fig. 45, or the outer 3 may be green and sepal-like and the inner 3 petal-like, as in *Trillium* (Fig. 1). The parts of the perianth are usually separate, but in some cases they are united so completely that their number is indicated merely by lobes, as in the lily-of-the-valley (*Convallaria*). There are usually 6 stamens and they originate in two circles of 3 each. There are 3 carpels, united into one pistil, but in several of the genera the stigma is three-lobed, and in some there are 3 separate stigmas. The ovary has 3 placentas (Fig. 51) and usually 3 cavities (cells), though in some species there is only 1 cell. The ovules have two integuments, and this is a common monocot character.

The floral numbers may be represented by writing a floral formula in which the union of parts in any circle is represented by enclosing the number representing them in parenthesis. This parenthesis is used if there is any considerable amount of union, though it may not be complete, and in the case of carpels it may mean that they are united into one ovary, though the styles are separate. The floral formula for most of the Liliaceæ is: sepals, 3; petals, 3; stamens, 3 plus 3; carpels, (3). This is a typical pentacyclic flower, since there are 5 circles of organs, the stamens constituting 2 circles. Pentacyclic flowers are distinguished from tetracyclic ones in which the stamens constitute only one circle, as is the case in some of the dicots.

THE IRIS FAMILY.

The Iridaceæ (iris family) are herbs growing from thick, perennial, underground stems and having their leaves borne in two ranks enfolding each other lengthwise. The commonest representatives of the family in the United States are the various species of the genus *Iris*, most of which are known as blue flags, and several species of the genus *Sisyrinchium*, known by the common name of blue-eyed grass. The flowers are usually showy and may be either regular or

irregular. The pistil is formed of 3 carpels, indicated by the three-celled ovary and the 3 (sometimes 6) stigmas. The perianth consists of 6 parts, all petal-like, and is adherent to the ovary, being thus epigynous and the ovary inferior. There are 6 stamens and the anthers are versatile. In the genus *Iris* the style has 3 petal-like branches and the stigma is a lip near the apex of each.

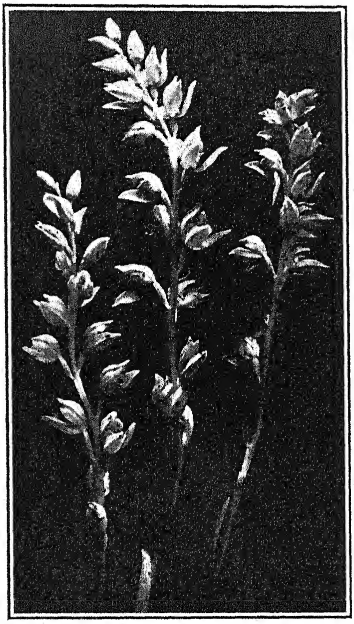

FIG. 134.—The snow orchid (*Cephalanthera austinæ*). (Photograph by J. B. Flett.)

THE ORCHID FAMILY.

The Orchidaceæ (orchid family) are perennial herbs characterized by remarkably irregular flowers. It is a large family represented in the flora of the United States by the lady-slipper (*Cypripedium*), the rattlesnake plantain (*Epipactys* or *Peramium*), the coral root (*Corallorrhiza*), and

other wild flowers, and also by many showy species cultivated in greenhouses. Some of the members of this family are saprophytes having only rudimentary roots. The perianth is adnate to the ovary, and is composed of 6 parts (sometimes only 5), all similar in texture, but one of the inner circle forms a lip or sac. There is usually only one fertile stamen, though in one genus there are two fertile ones and

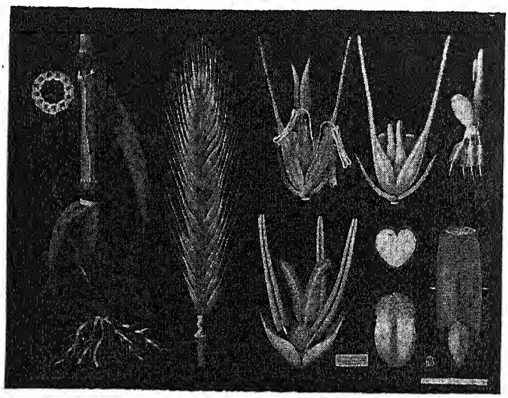

FIG. 135.—Rye. Left, a portion of the stem with leaves and roots. Also a cross-section of an internode, showing vascular bundles. Next, a "head" (spike) of rye before blossoming. Upper center, a blossoming spikelet, consisting of two fertile blossoms and one (middle) barren blossom. Next to the blossoming spikelet is a ripe spikelet with glumes and two ripe grains. Upper right, portion of young plant, showing roots with root hairs. Lower right, a ripe grain, with half-ripe grain and a cross-section of the grain at the left. (From Schmeil Botanical Charts.)

a rudiment of a third. The pollen sticks together in masses. The stamens are borne on the pistil and the ovary is thus inferior. The pistil is usually composed of 3 carpels and has 3 placentas bearing numerous ovules. The fruit is a one-celled capsule, opening by 3 valves. The flowers are pollinated by insects, and their striking irregularity is correlated with insect visits.

THE SEQUENCE OF FAMILIES.

The morphological sequence of these families is decided mainly on the basis of various floral characters, all of which are given due consideration in placing each family. The following list includes some of the characters to which most weight is given, the first character of each pair being regarded as low (simple) and the second as high (complex): (1) Indefinite numbers of floral parts; definite numbers of floral parts. (2) Imperfect flowers; perfect flowers. (3) Flower parts arranged spirally within the flower; flower parts arranged in cycles (circles) within the flower. (4) No perianth; perianth present. (5) Superior ovary; inferior ovary. (6) Regular flowers; irregular flowers. (7) Wind pollination; insect pollination.

On the basis of these characters it is evident why the Typhaceæ have been placed lowest in the sequence of families of monocots and the Orchidaceæ highest. The characters involved in all of the pairs except (3) are readily observed, but whether the flower is spiral or cyclic is often not so obvious. The flower parts in the dicots and the more complex monocots are arranged in definite cycles (circles), while in the simpler monocots they are arranged spirally. This spiral arrangement of sporophylls is seen also in the Gymnosperms, and is especially obvious in the ovulate cones (strobiles) of the conifers. The spiral arrangement of the parts in the flower thus separates the simpler monocots, such as the Typhaceæ, the Gramineæ, the Palmæ, and the Araceæ from the more complex ones, such as the Liliaceæ and the Orchidaceæ, and suggests a relationship of these simpler monocots with the Gymnosperms. It must be remembered, however, that no one character such as this can be taken alone as indicating actual close relationship of these simpler monocots with the Gymnosperms.

Such an arrangement of families as this does not necessarily mean that the families placed lowest in the sequence have never progressed farther in evolutionary development, for they may be reduced, or degenerate, descendants of plants that had once reached a higher level, and simple characters

are not necessarily primitive characters. The arrangement of orders and families for all groups of plants is known as the Engler sequence, and in the monocots there is quite general agreement that it represents the order of development within the group, though some workers disagree with placing the monocot group below all of the dicots.

Suggestions for Further Reading.

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3. Pool, R. J.: Flowers and Flowering Plants: An Introduction to the Nature and Work of Flowers and the Classification of Flowering Plants, New York, 1929.

4. Strasburger, E.: Textbook of Botany 5th ed. (English), London, 1921.

5. Swingle, D. B.: A Textbook of Systematic Botany, New York, 1928.

CHAPTER XXI.

THE DICOTS.

On the basis of their flower characters the Dicots fall naturally into two groups: (1) the Archichlamydeæ, which either have no corolla at all or have the petals separate from one another; and (2) the Sympetalæ, which have the corolla all in one piece, the individual petals being represented by lobes. The latter are sometimes spoken of as having united petals, but this means that the petals have fused in the evolution of the group and not that they were necessarily formed separately in the individual flowers. The Archichlamydeæ have two integuments on the ovule, while the Sympetalæ usually have only one.

THE ARCHICHLAMYDEÆ.

The discussion of four families whose plants are common in the United States and other north temperate regions will suffice to give a general idea of the characters of this group and of the lines of advance within it. There are in the world 198 families of this group and they comprise 26 orders.

The Willow Family.—The Salicaceæ (willow family) comprise two genera, *Salix* (willows) and *Populus* (poplars, aspens, and cottonwoods). They are trees or shrubs with imperfect flowers borne in catkins (aments) (Fig. 136), the staminate and pistillate flowers being with rare exception on separate plants. There is no true perianth, but each flower has a scale-like bract. There is commonly only 1 pistil to each scale and it has 2 to 4 placentas and 2 stigmas, which are sometimes two-lobed. There are commonly 2 stamens to each scale, though the number varies from 3 to 5 or more in one group of species, and in a few species there is only 1. The fruit is a one-celled pod having 2 to 4 valves. The

buds of *Populus* are protected by several overlapping scales, while those of *Salix* have a single scale covering the whole bud.

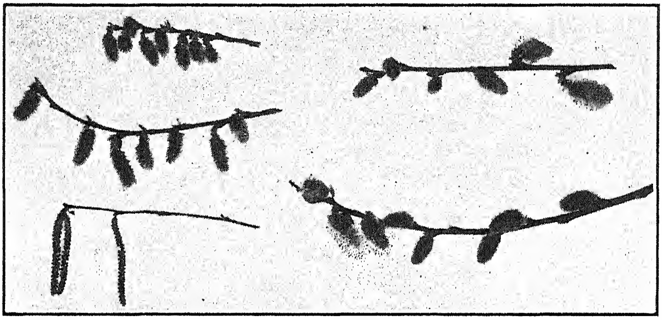

FIG. 136.—Catkins (aments). Upper left and middle left; pistillate catkins of willow. Right, staminate catkins of willow. Lower left, staminate catkins of hazel.

The Crowfoot Family.—The Ranunculaceæ (crowfoot family) are mostly herbs and include the buttercups (*Ranunculus*), columbines (*Aquilegia*), the larkspurs (*Delphinium*), and the anemones (*Anemone*). The flowers are perfect and have a perianth consisting of both calyx and corolla or of calyx only. When the corolla is wanting the calyx is often colored like a corolla. The number of sepals is indefinite, varying from 3 to 15, and the number of petals varies within about the same limits. The stamens are usually numerous and unconnected, and the pistils are the same.

The buttercups (*Ranunculus*) (Fig. 47) are familiar representatives of the family. They frequently have 5 petals and 5 sepals, though the number of both varies. The stamens and pistils are numerous, and each pistil is composed of a single carpel, there being only 1 cell and 1 ovule in the ovary. The fruit is small, dry, one-seeded, and indehiscent, and is thus an akene. All of the parts of the flower are borne on the receptacle (hypogynous), no circles are united, and there is no union of parts within any circle. The floral formula is: sepals, 5, but varying; petals, 5, but varying;

stamens indefinitely numerous; carpels indefinitely numerous. The family Ranunculaceæ belongs to the order Ranales, and this order is usually thought of as having the type of flower from which many other dicots may have arisen.

The Rose Family.—Among the plants included in the Rosaceæ (rose family) are the roses (*Rosa*), the strawberries (*Fragaria*), and blackberries (*Rubus*), the cotoneasters (*Cotoneaster*), the apples and pears (*Pyrus*), *Spiræa* (Fig. 137), and the plums and cherries (*Prunus*). The family includes herbs, shrubs, and trees, and all have alternate leaves which, except in a very few species, have stipules. The flowers are regular and in most species they are perfect. The calyx usually consists of 5 sepals, though in some cases they vary from 3 to 8, and they are united at the base. The petals (rarely wanting) are of the same number as the sepals and are borne on the calyx tube. The stamens are numerous and are borne with the petals on the calyx tube (Fig. 48). The number of pistils varies from one to many, and where there are many each is usually composed of a single carpel. In some species, however, there is only one carpel, and it, of course, forms a single fruit. When the pistils are united they are frequently combined with the calyx tube. The floral formula is: sepals, 5, but varying; petals, 5, but varying; stamens indefinitely numerous; carpels, 1 to several, separate or united.

The Pulse Family.—Among the plants included in the Leguminosæ (pulse family) are beans (*Phaseolus*), garden peas (*Pisum*), sweet peas (*Lathyrus*), clovers (*Trifolium*), alfalfa (*Medicago*), the vetches (*Vicia*), the lupines (*Lupinus*), and the broom (*Cytisus*). They are herbs, shrubs, or trees having alternate leaves, usually compound, with stipules. The flowers are irregular in nearly all of the species, and the irregularity is of a definite type not found in other families. There are 5 petals; 1 (the standard) has an erect portion at its tip, 2 others are somewhat united, forming the keel, and the other 2 are wings at the sides of the flower. This is technically known as a papillionaceous corolla, and its appearance is so striking that plants whose flowers have it can at once be recognized as belonging to this family.

There are 10 stamens, rarely united by their filaments into one group, though in most species 9 of them are so united and 1 is separate. The style and the stamens are usually bent sharply, near their ends, toward the standard.

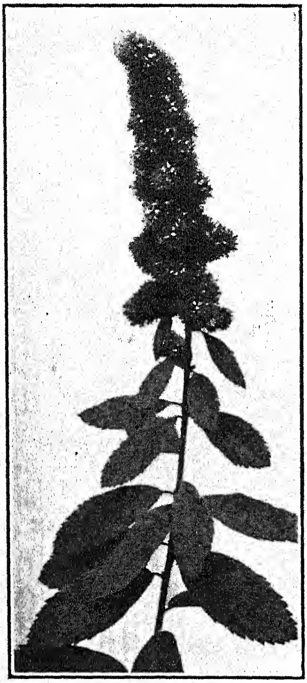

FIG. 137. — A leafy stem of spiræa (*S. Douglasii*) with a dense panicle of flowers. (Photograph by Chapman.)

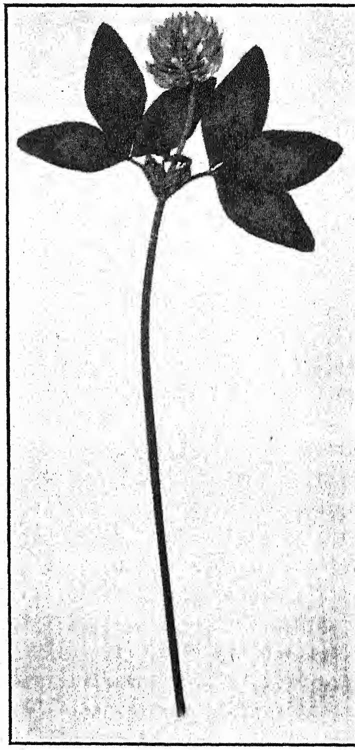

FIG. 138.—Red clover, showing head of flowers, and two compound leaves with stipules.

There is 1 pistil, which usually forms a one-celled pod, splitting open by 2 sutures. A flower of this kind is called zygomorphic, since it can be divided by only one plane of symmetry, as opposed to actinomorphic flowers, such as

those of the Ranunculaceæ, which are radial in structure and may thus be divided into similar halves by two or more longitudinal planes. The flowers of the Leguminosæ are insect-pollinated, and their irregularities are correlated with insect visits. This character makes them prominent in the Archichlamydeæ in the same way that the Orchidaceæ are prominent in the monocots.

The inner integument of the ovule is entirely absorbed as the seed develops, and the seed has only one coat.

The Parsley Family.—The Umbelliferæ (parsley family) are herbs with hollow stems and alternate leaves, usually compound, with a large sheathing base formed by the expanded base of the petiole. They are distinguished also by the fact that their flowers are very small and numerous and are arranged in conspicuous umbels (Fig. 139) at the top of the plant. These features are so plain that most of the species may be readily recognized even in the field as belonging to the family. A few species have the flowers in a head, but the umbel is the characteristic inflorescence of the family. Carrots (*Daucus*), parsnips (*Pastinaca*), celery (*Apium*), and parsley (*Petroselinum*) are representative cultivated plants of this family and sweet cicely (*Osmorhiza*) (Fig. 139); poison hemlock (*Conium*) and many other common large weeds of low grounds are representative wild ones. Most of the plants of this family have a characteristic aromatic odor, as is illustrated by celery and caraway. Though a number of representatives of this family, such as carrots and parsnips, furnish human food, a considerable number of wild ones are poisonous.

The calyx is composed of 5 united sepals, the union in some species being so complete as to show no lobes. There are 5 stamens inserted with the 5 petals on a disk over the ovary, and the ovary is thus inferior. The pistil is composed of 2 carpels, and has 2 styles and a two-celled ovary, each cell with 1 ovule. The fruit, when ripe, separates into 2 one-seeded dry parts, called mericarps, marked by longitudinal ribs and by oil tubes containing volatile oil which gives them the characteristic odor. The seed is enclosed in tissues derived mainly from the ovary wall, both of the

integuments of the ovule except a few layers of cells from the outer one having disappeared in the development of the seed.

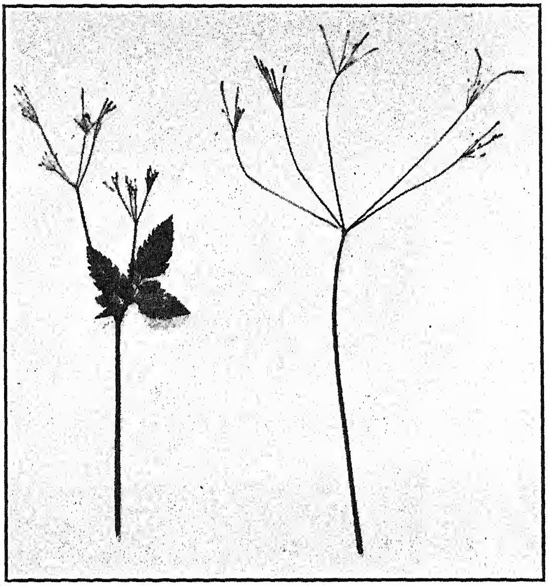

Fig. 139.—Sweet cicely (*Osmorhiza*), showing compound umbels.

The Sequence of Families.—Applying the same principles that we did in the monocots, it is evident why these families are arranged in this sequence. The Salicaceæ with their imperfect flowers, having no true perianth and indefinite floral numbers, and the staminate and pistillate flowers usually borne on separate plants are obviously low in the group, while the Umbelliferæ with their perfect flowers, united sepals, inferior ovary, and definite floral numbers are high. There are in the world 5 families below the Salicaceæ, but they are, in the main, not represented in the United States. One family, the Cornaceæ (dogwood family) is higher than the Umbelliferæ, and it is represented in the

United States by a number of species of dogwood trees, both wild and cultivated, and by the bunchberry, a herbaceous plant with perennial underground stems.

THE SYMPETALÆ.

There are 57 families of the Sympetalæ, comprised in 11 orders, but a discussion of 7 families—the lowest, 5 intermediate, and the highest—will suffice to illustrate the characters of the group and the lines of advance within it.

The Heath Family.—The Ericaceæ (heath family) (Fig. 140) are mostly shrubs with regular flowers, though the family includes some herbs and some plants with irregular flowers. Many of the family (*e. g.*, the heathers, and most of the rhodondendrons) are broad-leaf evergreens, some (*e. g.*, the Indian pipe) are herbaceous saprophytes, and some (*e. g.*, pine drops) are herbs parasitic on the roots of woody plants. Other plants belonging to the family are the laurels (*Kalmia*), the trailing arbutus (*Epigæa*), the blueberries and huckleberries (*Vaccinium*), and the wintergreens (*Pyrola* and some species of *Gaultheria*).

The calyx is composed of 5 sepals, separate or united, and the corolla of 5 petals also separate or united. The stamens are of the same number or twice as many as the petals or the corolla lobes. The anthers are two-celled, and in many of the species they open by a pore at the end, and some have a characteristic appendage. In most of the genera 4 pollen grains are united, forming compound pollen. There is 1 pistil with 1 style, and the ovary contains from 3 to 10 cells. The ovary is inferior in some of the genera and superior in others.

The Gentian Family.—The Gentianaceæ (gentian family) are herbs with opposite leaves which are sessile and entire and have no stipules, and are simple in all of the genera except one. The gentians (*Gentiana*) are the most familiar representatives, and several species of centaury (*Centaurium*) and one species of buckbean (*Menyanthes*) are found in many parts of the United States. The flowers are regular and the petals are united. The floral number varies from 4 to 12,

but is quite commonly 4 or 5, and the stamens are of the same number as the corolla lobes and are inserted on the corolla tube. There is only 1 pistil and the ovary is one-celled and usually has 2 placentas, though the ovules in some species are scattered over the inner surface of the ovary.

FIG. 140.—A rhododendron (*R. californicum*).

The fruit of most of the species is a capsule splitting by 2 valves and having many seeds.

The Morning Glory Family.—The Convolvulaceæ (morning glory family) include the morning glories (*Ipomœa*), the bindweeds (*Convolvulus*), the sweet potato (*Batatas*), and

the various species of dodder (*Cuscuta*). Most of the species are twining or trailing herbs with alternate leaves, which are reduced to scales in some. The flowers are regular and usually showy. There are 5 sepals (usually somewhat united) and 5 stamens, and the corolla is five-lobed. In some species there is 1 pistil with usually 2 cells and 2 placentas, while in others there are 2 separate pistils. The fruit is a few-seeded capsule.

The Mint Family.—Most of the species of the Menthaceæ (mint family) are herbs and are recognized by their square stems, opposite leaves, and irregular flowers with two-lipped corolla. The leaves of many of the species are aromatic, because of the presence of volatile oil, which occurs in numerous small glands. The calyx is composed of 5 united sepals and the corolla is five-lobed, 2 of the lobes being on the upper lip and 3 on the lower one. There are mostly 4 (sometimes 2) stamens, and they are borne on the tube of the corolla. The ovary is four-celled and deeply four-lobed, and separates into 4 one-seeded fruits when mature. The style is two-lobed. The family includes the mints (*Mentha*), horse mints (*Monarda*), skullcaps (*Scutellaria*), horehound (*Marrubium*), sage (*Salvia*), thyme (*Thymus*), and many other familiar plants.

The Figwort Family.—The Scrophulariaceæ (figwort family) include, among other plants, the snapdragons (*Antirrhinum*), the mulleins (*Verbascum*), figworts (*Scrophularia*), the beard-tongues (*Pentstemon*), the monkey flowers (*Mimulus*), the painted cups (*Castilleja*), the louseworts (*Pedicularis*), and the foxglove (*Digitalis*). They are mostly herbs characterized by a more or less irregular corolla (often two-lipped), 4 stamens in 2 pairs of unequal length, and a two-celled ovary containing many ovules on 2 placentas in the axis. In having the ovules on an axis growing from the base of the ovary, they differ from many other families, which have the ovules borne on the ovary wall. The seeds have a small embryo and a large endosperm.

The Honeysuckle Family.—Among the plants belonging to the Caprifoliaceæ (honeysuckle family) are the honeysuckles (*Lonicera*), the snowberries (*Symphoricarpos*), the twin-flower

(*Linnæa*), the high-bush cranberry (*Viburnum*), and the elders (*Sambucus*). They are mostly shrubs with opposite leaves. The calyx is composed of 4 or 5 united sepals, and the corolla is five-lobed. The ovary is inferior and has from 2 to 5 cells. The stamens are usually of the same number as the lobes of the corolla and are inserted on its tube. The floral formula is: sepals, (4) or (5); petals, (4) or (5); stamens, 4 or 5; carpels, (2) to (5).

The Composite Family.—The Compositæ (composite family) constitute the highest family of the plant kingdom and the largest family of seed plants. The ones found in the United States are mostly herbs. Among the common plants of this family are the sunflowers (*Helianthus*), asters (*Aster*), golden-rods (*Solidago*), gum-plant (*Grindelia*), fleabanes (*Erigeron*), cudweeds (*Gnaphalium*), ragweeds (*Ambrosia*), daisies (*Bellis* and other genera), and the dandelion (*Taraxacum*). The inflorescence and fruit of the dandelion are shown in Fig. 55 and a single flower in Fig. 56.

The flowers are in a close head on a common receptacle, and the head is surrounded by an involucre of bracts. In some (*e. g.*, dandelion) the flowers are all alike, while in others (*e. g.*, sunflowers) they are of two kinds, ray flowers and disk flowers; the disk flowers having tubular corollas and the ray flowers strap-shaped (ligulate) corollas. In both kinds the corolla has 5 lobes or teeth. The calyx, corolla, and stamens are all borne on top of the ovary and the ovary is, therefore, inferior. The ovary has 1 cell and 1 ovule. There are usually 2 recurving stigmas. There are 5 stamens and they are united by their anthers (syngenesious), forming a ring or tube around the style. The free portion of the calyx is commonly modified into a circle of numerous hairs called the pappus (Fig. 56), which persist on the fruit (Fig. 54) and enable it to be distributed widely by the wind. In some cases, however, the free portion of the calyx is represented by mere scales and in others it is entirely lacking.

The fruit is small, dry, and one-seeded. The integuments of the ovule disappear entirely in the course of the development of the seed, and the mature seed is enclosed in a structure derived from the ovary wall only. The floral formula

for the family is: sepals, united at the base, the free portions being indefinitely numerous and reduced to a pappus; petals, (5); stamens, 5; carpels, (2), so far as indicated by the two stigmas, but degenerated into one so far as the ovary is concerned.

The Sequence of Families.—In addition to the principles already stated under the discussion of monocots (p. 303) on which the sequence of angiosperm families is arranged, the following may be mentioned, the first character of each pair being regarded as low (simple) and the second as high (complex): (1) Flowers loosely arranged; flowers massed. (2) Calyx composed of ordinary sepals; calyx modified into a pappus. (3) Five circles of organs in a flower (pentacyclic); four circles of organs (tetracyclic). (4) Carpels forming separate pistils (apocarpic); carpels united into one pistil (syncarpic). (5) Two seed coats; one seed coat or no true seed coats, the seed being enclosed in tissues derived from the ovary wall.

The Compositæ have high (complex) characters on the basis of all of these principles, while the 6 other families considered have some high and some low (simple) ones.

Suggestions for Further Reading.

The books listed under Chapter XX.

CHAPTER XXII.

PLANT BREEDING AND GENETICS.

PLANT BREEDING.

PLANT breeding is extensively carried on both as pure science and as a means of producing new varieties of economic importance. It is a very old practice, having been used by the Chinese in ancient times, and has been used systematically in Europe and America for about one hundred and fifty years.

Cross-breeding is carried on by a careful transfer of pollen from the anthers of one variety to the stigmas of another variety, care being taken to guard against the presence of any other pollen than the one being transferred. A plant produced by cross-breeding is known as a hybrid, and the process of cross-breeding is called hybridization. Though crosses are most commonly made between varieties of the same species, some success has been attained with crosses between species of the same genus, and a few crosses between species of different genera have been produced.

Hybridization of varieties may be illustrated by the sweet pea (*Lathyrus odoratus*), the varieties of which have been systematically cross-bred since about 1880, and corn (*Zea mays*), in which hybridization has been extensively practised for a number of years. Crosses between species of the same genus have been produced in snapdragons (*Antirrhinum*) and also in tobacco (*Nicotiana*), and other plants. Crosses between species of different genera are less common, but successful intergeneric hybrids have been produced in orchids, and a hybrid between corn and teosinte (*Euchlæna luxurians*) has been secured. Teosinte is a perennial grass somewhat resembling corn and grows vigorously, producing numerous stems from one plant.

Hybridization has shown its best results when carried on in connection with careful selection of individual plants showing desirable qualities, and vegetative propagation has often been used as a means of perpetuating good characters. Many species and varieties tend to vary in their character (see p. 329), as is illustrated by corn, in which variation is so common that constant selection is necessary in order to keep a desirable variety. Occasional larger variations, known as mutations (see p. 330), occur in some plants, as is illustrated by sweet peas, in which varieties with white flowers have arisen by mutation from a variety with colored flowers. It is well known that budding, grafting, and the use of cuttings often perpetuates desirable qualities better than reproduction by seeds, and these methods are commonly used with plants whose form and structure adapt them to such treatment. The number of varieties of plants produced and perpetuated by the various experimental methods is enormous, and it has been stated that over 5000 varieties of cultivated plants have been produced from about 30 species.

Hybridization is most readily carried on with plants whose stamens and pistils are in separate flowers, and corn has been used extensively for such work. The stamens are in the tassel at the top of the plant and the pistils (silks) are in the ear on the side of the stem some distance from the top. In cross-pollenizing this plant an ear is covered with a paper bag before the silks appear, and pollen is collected by placing a bag over the tassel of a plant of a different variety. Pollination is then effected by removing the bag from the ear and replacing it with the bag containing the pollen. This method is sure but is somewhat tedious, and various field methods are used for securing cross-pollination on a larger scale.

In perfect flowers whose stamens and pistils mature at the same time the anthers must be removed before they are mature. Pollen from another variety may then be transferred to the stigma of this flower with a small camel's hair brush or by other suitable means. In the sweet pea the anthers and stigma are close together within the flower, and

cross-pollination in the way mentioned is commonly practised. Cross-pollination is a very interesting field for experimentation, and the details of the various methods used may be found in the many books on plant breeding.

Two qualities, vegetative vigor and a tendency to self-sterility, are important in hybrids. It has been known for more than one hundred years that some hybrids display unusual vegetative vigor, and the work of more recent years has greatly extended the list of hybrids in which this occurs. A cross between two species of mullein (*Verbascum*) produces stems that are taller than those of either parent, and great increase in height over that of the parents is also shown by a hybrid between two species of *Lobelia*. Some hybrids show increased vegetative vigor in other ways than mere increase in size, such, for instance, as an increase in the number of side branches either aërial or underground.

Increased vegetative vigor is not, however, universal among hybrids, and many examples are found which show decreased vigor. Within the same genus it is found that some interspecies crosses produce increased vigor while others produce decreased vigor, as is illustrated by tobacco and also by mullein.

GENETICS.

Attempts to discover the laws which operate in the production of new qualities in cross-breeding and interest in the relation of this to the problems of evolution gave rise to the science of genetics, and much progress has been made in this science, by the use of both plants and animals. Among the most notable of such results is Mendel's law, on the basis of which we are able to predict certain qualities of hybrids from knowing those of the parents. Gregor Mendel was an Austrian monk, and was experimenting with peas in the garden of the monastery, only a few years after the time when Charles Darwin was accumulating data and formulating his theory of evolution. His work was published in 1865, but no attention was paid to it until 1900, when attention was called to it about the same time by three

different European investigators, and it is now recognized as being of fundamental importance.

Mendel made a careful study of the work of other plant breeders, and sought to find the reasons for their successes and their failures. He used garden peas, and for his experiments, covering a period of eight years and involving several thousand individual plants, he selected plants that showed striking contrasts in certain characters, such as tallness and shortness of stems, form of pods, and color of seed coats. This is not a complete list of the characters with which he experimented, but the three mentioned will illustrate his method of work.

Such characters were found to behave as unit characters, and he experimented on them one pair at a time, making crosses between: (1) tall plants and dwarf plants; (2) plants with inflated pods and those with deep constrictions between the seeds; and (3) plants with white seed coats and those with darker colors. He found that in each pair one character was dominant, tallness, for example, being dominant over dwarfness, and the two contrasting characters are designated as dominant and recessive.

He found that in crossing tall and dwarf peas all of the first hybrid generation were tall, and that when these were inbred three-fourths of the next generation were tall and one-fourth dwarf. These dwarf plants continued, generation after generation, to produce dwarf plants. One-third of the tall ones produced tall plants which continued to produce tall plants generation after generation. The remaining half of these second generation hybrids produced tall and dwarf plants in the proportion of 3 to 1, the dwarf plants producing dwarf plants in future generations, and one-third of the tall plants producing tall plants in future generations while the remaining half of the generation produced tall and short plants in the same proportion and showing the same progeny-producing qualities as the preceding generation.

It is thus seen that three kinds of plants are produced in the second hybrid generation by this cross: (*a*) those with the dominant character, breeding true; (*b*) those with the

recessive character, breeding true; and (*c*) those which themselves showed the dominant character, but also possessed the recessive character, and that the numbers of these are in the proportion 1*a* to 2*c* to 1*b*. If we represent tallness by a long line and dwarfness by a short one, and use *D* to indicate the dominant character and *R* the recessive one, putting the *R* in parenthesis where it is possessed by an individual which itself shows only the dominant character, and indicate cross-breeding by the multiplication sign, we may illustrate Mendel's law by a diagram (Fig. 141).

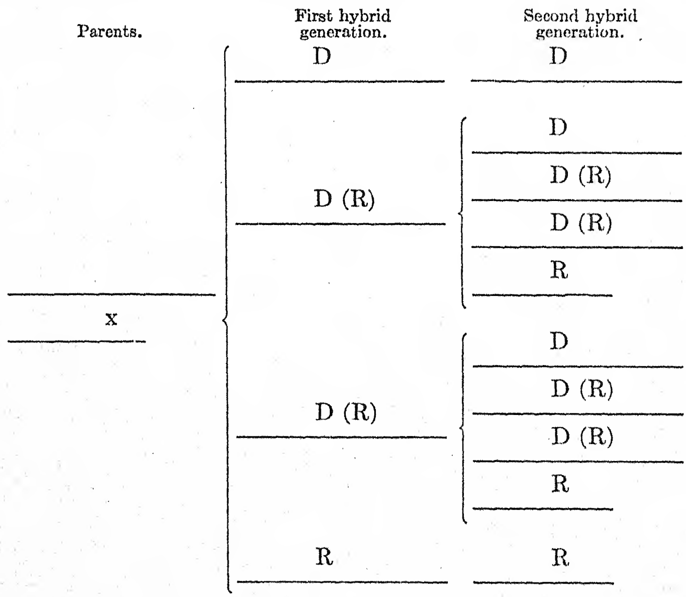

FIG. 141.—Diagram to illustrate Mendel's law. Explanation in text.

So far we have discussed crosses between plants showing only one contrasting character, and the cases become less simple when we consider crosses between plants showing contrasts in two or more of the unit characters. Mendel used, in all, seven different pairs of contrasting characters, and found that in all of these one character of each pair was

dominant over the other and that there were no intermediates. He further found that each character behaved as a unit and was not influenced by the other characters. When he crossed tall, yellow-seeded plants with dwarf green-seeded ones, tallness and yellow-seededness were dominant over dwarfness and green-seededness. Further details of his work may be found in the books listed at the close of this chapter.

Many workers have experimented with hybridization of peas from 1900 down to the present time, and their results have confirmed those of Mendel. Such work is an excellent illustration of the inductive method in scientific work, since the generalization, or law, is arrived at by the accumulation of large numbers of cases all of which agree, and finding that none disagree. For instance, in seed color of peas over 180,000 cases have been recorded, and in all of them yellow was dominant over green and the average of these varies from the expected ratio of 75 to 25 per cent by less than 1 per cent.

Not all plants, however, show this dominance in the first generation hybrids. Many hybrids are blends showing characters intermediate between those of the parents, and these seem at first thought to be very different from the pea hybrids discussed above. In crossing two varieties of four-o'clock (*Mirabilis jalapa*) it has been found that flower color is a blend between that of the parents, rose-pink flowers being produced by a cross between red and white. Although the first generation appeared different from the Mendelian case in not showing dominance of the character of one parent, it was found that by inbreeding the rose-pink plants the Mendelian ratio, 1 to 2 to 1, was obtained in the next generation.

Mendelism has been accepted as the working hypothesis of genetics, and will undoubtedly continue so unless experimental evidence is found to overthrow it. Though it has not yet been shown that all inheritance in plants and animals is Mendelian, no other satisfactory explanation has been found.

Naturally an explanation of how characters are transmitted according to Mendel's law was sought, and a fairly satisfactory explanation was found in the behavior of the chromo-

somes (see pp. 26 and 27). Since in the division of vegetative cells resulting in the production of more vegetative cells each chromosome divides into two equal parts, and one half goes into each of the new cells, they furnish a visible mechanism by which characters may be transmitted from one vegetative cell to another, and this view is strengthened by the fact that no other visible bodies contribute equally to the two new cells.

The behavior of the chromosomes in sexual reproduction is different from that seen in the formation of vegetative cells. When gametes unite the number of chromosomes is doubled. In fertilization the number of chromosomes in the oöspore is twice as many as in the egg or the sperm; if there are 3 in the egg and 3 in the sperm there will be 6 in the oöspore. The number is reduced at some other point in the life history. In plants showing an alternation of generations this correlates with the presence of the x (haploid) number of chromosomes in the gametophyte and the 2x (diploid) number in the sporophyte.

The nuclear unions which result in the doubling of the chromosomes and the nuclear divisions in which the number is reduced are important points in the study of genetics. In the reduction division the chromosomes unite in pairs and then separate, one of each pair going to each of the two new nuclei, but there is considerable difference of opinion in regard to the details involved. An excellent discussion of these details and their possible interpretations is presented in Sharp's *Introduction to Cytology*.

Each chromosome seems to be made up of definite particles, called genes, and it is believed that the factors in inheritance are carried by these genes, and that inheritance is a matter of the physical and chemical properties of these minute particles of living matter. Satisfactory diagrams can be made which are consistent with the facts observed in Mendelian inheritance.

The chromosome theory is commonly accepted, though there is some hesitation, particularly among biochemists, about regarding it as a full explanation. It is thought possible that substances not in the chromosomes or even not

in the nucleus may have their influence in heredity, but there is not sufficient information available at present to furnish a satisfactory basis for any explanation other than the chromosome theory. It seems best to use this theory, but at the same time to preserve an open mind as to the possibility of other factors operating also, and likewise to look forward hopefully to further knowledge of the chemical nature and the physical organization of chromosomes which may throw light on the transmission of characters from one cell to another.

Suggestions for Further Reading.

1. Coulter, M. C.: Outlines of Genetics: With Special Reference to Plant Material, Chicago, 1923.
2. Castle, W. E.: Genetics and Eugenics, Cambridge, 1920.
3. Babcock, E. B., and Clausen, R. E.: Genetics in Relation to Agriculture, New York, 1918.
4. Sinnott, E. W., and Dunn, L. C.: Principles of Genetics, New York, 1925.
5. Sharp, L. W.: An Introduction to Cytology, New York, 1921.
6. Walter, H. E.: Genetics: An Introduction to the Study of Heredity, New York, 1922.
7. Weatherwax, P.: The Story of the Maize Plant, Chicago, 1923.

CHAPTER XXIII.

THE EVOLUTIONARY POINT OF VIEW.

THAT all plants showing any complexities of structure have originated by modifications of simpler forms is generally believed by people who are familiar with the structure and the methods of reproduction of plants. This assumes a living cell to start with and there has been much speculation as to how life originated. Many believe that living matter evolved from non-living matter which was in the colloidal state (see p. 24), and that the transition from non-living to living matter was a gradual one. The probability of the existence of non-cellular forms of life (see p. 212) lends some support to this theory, but we possess no definite proof as to the way in which living matter originated.

The doctrine of the evolution of plants is an inference based on a very large number and variety of facts determined partly by observation and partly by experiment, and these furnish such satisfactory evidence for the doctrine that practically all botanists believe in it. The evidence for evolution among animals is even more striking than that among plants but we shall here discuss only the plant evidence.

Among the general lines of evidence on which the doctrine of evolution is based are the following: (1) The obvious similarities in certain features of all complex plants to simpler ones. (2) The tendency of all species to vary in form and structure. (3) The modification of species and varieties by cross-breeding. These will be discussed in the order listed.

1. RELATIONS BETWEEN COMPLEX PLANTS AND SIMPLER ONES.

All plants can be arranged in a fairly continuous series of increasing complexity of form and structure as to both

vegetative and reproductive organs. The contrast between a one-celled blue-green alga with its very simple organization even within the cell and a species of the composite family of seed plants with its highly specialized vegetative and reproductive organs is a striking one, but when we view this contrast in the light of all of the groups that come between them, each showing just a little more complexity than the ones immediately below it, the idea that such complex forms may, through a very long period of time, have developed from such simple ones seems probable. It does not seem probable, however, that the least specialized members of any group have originated from the most highly specialized members of the group immediately below it, but rather that both have a common origin in less specialized and more plastic forms below them.

The Relation of the Four Divisions.—The four divisions are fairly distinct and are separated on technical characters for convenience, but the break between any two divisions is not great when all of the characters of the highest (most complex) plants of any one division and all of the characters of the lowest (simplest) plants of the next one above it are considered. We may separate the Bryophytes from the Thallophytes on the basis of one character (the multicellular egg-producing structure, p. 244) but on the basis of other characters the separation would not be sharp, and we have one family (the Characeæ, p. 190) which shows such transitional characters between the two that it is difficult to place it satisfactorily in a scheme of classification.

When we attempt to separate the two groups of Bryophytes (liverworts and mosses) from each other we find no one character (see p. 254) which will serve, but are forced to use a combination of three characters, all of which are sometimes found in both groups but serve as a basis of separation when all three occur together.

We separate the Pteridophytes from the Bryophytes by the fact that the sporophyte of the former possesses vascular tissue and becomes independent of the gametophyte after a very brief period of connection, but when we consider all of the characters of the most complex sporophytes in the

Bryophytes and compare them with the simplest sporophytes of the Pteridophytes we find some transitional characters. The sporophytes of many of the mosses (p. 249) and of some of the liverworts (p. 246) possess chlorophyll and are thus able to manufacture their own carbohydrate food. Since the sporophyte is thus at maturity dependent on the gametophyte merely for water and mechanical support there is a clear tendency toward its independence. There are also certain structural tendencies about these sporophytes of the higher Bryophytes which point toward those of the Pteridophytes, since they have stomates and have elongated, though not otherwise specialized, cells in the central portion of the stalk which facilitate the transfer of water.

For many years the break between the Spermatophytes and the Pteridophytes seemed to be very sharp, but the discovery of fossil plants (p. 290) that produced seeds but showed decidedly Pteridophyte characters in their vegetative organs has rather completely bridged this gap.

The Sequence of Families.—When we consider the plant kingdom from the standpoint of its orders and families the evidence for the gradual transition from the lowest to the highest is even more convincing than when we consider the four divisions. The Engler sequence of families includes all of the families of plants from the lowest Thallophytes to the highest Spermatophytes and is in general a satisfactory one. It is commonly used by botanists though there are some differences of opinion as to the placing of certain groups.

One instance of the tendency to modify the arrangement of families as stated by Engler in the 1904 edition of his work, Syllabus der Pflanzenfamilien (Syllabus of Plant Families), is the placing of the group of families constituting the common ferns (*Filicales*). Engler placed these families low among the Pteridophytes, but they are now commonly placed highest. There is general dissatisfaction also with placing the Monocots below all of the Dicots, though they are still commonly placed in this position because no entirely satisfactory position has been found for them.

The sequence of plant families is based on certain specific characters of form and structure which point to the develop-

ment of the more complex plants from the simpler ones. It would be impossible to discuss within the limits of an elementary textbook all of these lines of development, but they may be illustrated by a brief statement of the more outstanding facts under the two heads: (*a*) the plant body; (*b*) the flower.

(*a*) *The Plant Body.*—Since the plant body in the seed plants and the ferns is the sporophyte, the evolution of the plant body must be traced within this generation. The evolution of the gametophyte is interesting but it must be regarded as a line of development that leads nowhere so far as the plant body of the higher plants is concerned, since it reaches its highest development in the Bryophytes (see pp. 247 and 255) and gradually declines in size from there to the microscopic gametophytes of the seed plants (see pp. 281 and 293).

The lines of evolution in the sporophyte may be illustrated by a consideration of the characters of the sporophytes of: (1) four liverworts (*Riccia, Marchantia, Porella,* and *Anthoceros*); (2) the common mosses (Bryales); (3) a club moss (*Lycopodium*); (4) a family of common ferns (*Polypodiaceæ*); (5) a family of Gymnosperms (*Pinaceæ*), and (6) the Angiosperms.

These have all been described and the lines of relationship may be traced here without repeating the descriptions. The series begins with a sporophyte consisting of a mere case of spores (*Riccia,* p. 244). The first stage of evolution is illustrated by the sporophyte of *Marchantia* (p. 244) which is differentiated into a foot, a stalk, and a capsule opening irregularly and containing elaters with the spores, and further progress is shown by that of *Porella* (p. 245) in which the capsule splits regularly by four valves in the discharge of its spores.

Important steps in advance are shown by the sporophyte of *Anthoceros* (pp. 246 and 247) which has a large amount of vegetative tissue as compared with the amount of spore-producing tissue, has stomates in its surface, and possesses chlorophyll. The sporophyte of the common mosses (p. 249) shows a slightly higher degree of complexity and a still greater

proportion of vegetative tissue as compared with spore-producing tissue.

The sporophytes of *Lycopodium* (p. 269) produce their spores in sporangia on the surface of green leaves and in some of the species these are grouped in a cone-like structure at the top of the plant. This is a distinct advance over the condition in the others described, in which the spore-producing cells are situated within the vegetative tissue.

The sporophyte of *Selaginella* (p. 270) has two kinds of spores, one kind producing the male gametophytes and the other the female, both kinds of spores being produced in a specialized cone-like structure at the tip of a stem or branch. This production of two kinds of spores suggests a close relation of this sporophyte to that of the spermatophytes, but when its vegetative structure is compared with that of the Polypodiaceæ (p. 256) the latter are placed higher though they have only one kind of asexual spores.

The sporophyte of the Pinaceæ (p. 276) shows distinct advances over that of the common ferns in stem structure and other vegetative characters, and also over that of *Selaginella* in having the asexual spores produced in more specialized sporangia on more specialized sporophylls. The sporophyte of the angiosperms (pp. 292 and 294) shows the most advanced stem structure (p. 268) found in the plant kingdom and also the most complex organs (pp. 280 and 281) for the production of the two kinds of spores (p. 281) which give rise to the male and female gametophytes.

These are merely a few illustrations of the evolution of the sporophyte and do not by any means indicate all the steps in its progressive development. A fairly full understanding of the steps may be had by reviewing the pages referred to in this text, and a still fuller understanding by reading some of the books on morphology listed at the end of Chapter XX.

(*b*) *The Flower.*—The flower (see pp. 103 and 106). is regarded as a modified branch and its parts as modified leaves. The stamens and carpels are modified so that they produce spores, and their relation to the sporophylls of seedless plants such as those of *Selaginella* is significant. The relation of cyclic flowers (p. 303) such as those of the Liliaceæ

and the Ericaceæ to spiral flowers (p. 303) such as those of the Gramineæ and the Palmæ, and the relation of the ovulate cones of the conifers (p. 283) to the flowers of the Monocots and the Dicots is also suggestive of evolutionary development.

It is difficult to frame a satisfactory definition of the term "flower." Since the essential organs of a flower are the sporophylls (stamens and carpels) we might define the term as a group of sporophylls and thus include the strobilus of *Selaginella*. If we define it as a structure having either stamens or pistils (see p. 105) or both we include merely the Angiosperms, while if we define it as a structure having sporophylls enclosed in a perianth we exclude some of this group. The difficulty encountered in defining the term indicates the lack of any sharp line of division between what we ordinarily think of as a flower and the groups of sporophylls found in the conifers and in some of the Pteridophytes. The lines of development involved can be traced by consulting the pages cited above, and some of the principles of the Engler sequence which are based on the flower and the inflorescence can be found on pp. 303 and 315.

2. VARIATIONS.

It is a matter of common observation that no two individual plants even of the same species are exactly alike, and the differences are often conspicuous. Differences in the size of the plants; in number, size, and form of the leaves; in the color of the flowers; and in the size of the fruit are among the variations that are frequently seen. The common shepherd's purse shows great differences in the height and relative thickness of its stems, and these can frequently be correlated with differences in environmental conditions, mainly of soil, moisture, and light. The rockweeds along the seashore often show variations in the length and width of the thallus which form a complete series from one species to another, and it is thus difficult to decide what is the actual boundary of either species. No correlation with environmental factors is evident in this case.

Labrador tea (*Ledum grœnlandicum*) shows great variation in the size of its leaves and the amount of hair on them. On plants growing in *Sphagnum* bogs the leaves are relatively small and have a dense covering of hair on the lower surface, while on plants growing in marshes and other wet places outside of *Sphagnum* bogs the leaves are larger and have much less hair. These differences are so great that the leaves of the swamp form often approximate those of another species (*L. columbianum*). Sassafras (*S. variifolium*) and the western wild crab-apple (*Pyrus diversiloba*) show great variation in the form of the leaves even on the same plant, some of the leaves being entire and others lobed. The pale laurel (*Kalmia polifolia*), also called swamp laurel, shows variations in the color of its flowers from pale pink to rose-purple. The size and color of apples on the same tree are often very different and the development of a red color is commonly associated with more direct exposure to light.

These differences are relatively slight but larger variations sometimes occur suddenly and where these are inherited a new species or variety originates by mutation (see p. 317). A notable case of this is the sudden appearance of individuals of Lamarck's evening primrose (*Œnothera lamarckiana*) which differed so much from the parent plants and when inbred retained these distinctive characters so well that they are recognized as new species. Many other mutants have occurred among plants. The Shirley poppy arose from the field poppy by mutation and a new form of tobacco differing from the parent plant in the number of leaves has arisen in the same way. It is supposed that Brussels sprouts originated in this way from wild cabbage and that the weeping form of the European beech came from the common form by this same sudden change.

Much attention has been given to the causes of variations but the cause of the variations giving rise to mutants has not been found. Many slight variations are due to environment, and many variations have also been found in which the differences can be accounted for by new combinations of genetic factors.

3. HYBRIDIZATION.

The production of new varieties of cultivated plants by cross-breeding is common (p. 316), and it is believed that many hybrids occur in Nature among wild plants. The fact that species are not fixed but may be greatly modified by selection and cross-breeding constitutes an important part of the evidence on which the inference that complex plants have originated from simpler ones is based. Work on plant evolution in recent years has been largely experimental, and much attention has been given to the production of hybrids and the study of their characters with a view to getting a better understanding of the possible mechanisms of heredity.

THEORIES OF EVOLUTION.

Theories as to *how* the evolution of plants has taken place should be carefully distinguished from the *facts* on which the general belief in the evolution of plants is based. Undoubtedly many factors have operated in the origin of complex plants from simpler ones. Among those believed in by various workers are: (1) the inherent tendency to variation; (2) the influence of environment; (3) the survival of the fittest in the struggle for existence; (4) the inheritance of acquired characters; (5) the disappearance of organs that are not used and the progressive development of those that are used; (6) the effects of isolation; (7) the continuity of the germ plasm and the possibility that the vegetative body is a mere product of this; (8) the possibility that there is within plants an inherent tendency or "urge" toward the production of more complex forms; (9) natural hybridization, and (10) the sudden appearance of new species and varieties by mutation.

Interpretations of the ways in which these different factors or combinations of them have operated constitute the various theories of evolution, and probably no one of them can be regarded as *the* explanation of evolution. The facts which constitute the basis of the belief in evolution can be correlated to a greater or less extent with the various theories, and the

strength and weakness of these theories can be best understood when both plants and animals are considered. It would be impossible to present all of these theories adequately in a brief textbook on botany, and the student is referred to the treatments of them presented in books such as those listed at the close of this chapter.

Suggestions for Further Reading.

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2. Cutler, D. W.: Evolution, Heredity, and Variation, London, 1925.
3. Conger, G. P.: New Views of Evolution, 1929.
4. De Vries, H.: Species and Varieties: Their Origin by Mutation, Chicago, 1905.
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CHAPTER XXIV.

BOTANICAL NAMES.

COMMON names of plants are very useful, and such names as rose, dandelion, fern, wheat, maple, and sage-brush are widely known and suggest with reasonable accuracy certain plants or groups of plants. Such names, however, though they are very useful in popular discussions and could not be dispensed with, do not meet all needs. It is desirable in addition to these common, or popular, names to have names that are more exact and are more generally understood by all persons, no matter what language they speak or write, who are trained in the science of botany or in any of the sciences or professions in which botany plays a part.

Among the reasons why common names do not meet the needs of such professionally trained persons are: (1) that the same name is often applied to more than one plant, and (2) that the same plant is often known by more than one name. Examples of the first are the name "sandbur" which in some places is applied to a troublesome weed belonging to the grass family, and in other places to a seaside plant belonging to the composite family and also to an inland species closely related to the latter; and the name "wintergreen" which is applied to several widely distributed species of perennial herbs belonging to the heath family, and also to a small evergreen shrub of the same family. Examples of the second are the redbud, which is also known as the Judas tree, and the Douglas fir, which is also known as red fir, Douglas spruce and Oregon pine.

The following may be mentioned as examples of the sciences and professions in which exact and internationally understood names for plants are necessary: forestry, agriculture, pharmacy, bacteriology, and biological chemistry.

Plants are named scientifically according to a system based on the Latin language and known as the binomial system, since each name is composed of two parts—the name of the genus and the name of the species. This system was put into use by Linnæus, the great Swedish botanist, in labeling the plants in his herbarium, and was published in his *Species Plantarum* (The Species of Plants) in 1753. The names of the genera had been used before this time, the custom being to distinguish the various kinds of plants by writing one or more descriptive words in Latin after the name of the genus. The number of words used in this system to distinguish what we now call a species varied from two to as many as six. In an old herbal published in England before the Linnæan system of naming plants had come into general use the marsh marigold is designated by the binomial *Caltha palustris*, while the large-flowered larkspur with the much divided leaves is called *Aquilegia magno flore foliis majus divisis*. A few years later the author of this herbal wrote a flora of England in which he used the binomial system of Linnæus.

In the binomial system the name of the genus is written first and is always capitalized. The name of the species is usually not capitalized. Some botanists prefer not to capitalize any specific names at all, but according to the rules generally followed there are three classes of specific names that are capitalized: (1) those that are derived from the names of persons; (2) those that were formerly the names of genera, and (3) a few that were capitalized by Linnæus, though the reason for the capitalization is not always known.

Examples of botanical names in which the species are not capitalized are *Solanum tuberosum* (potato), *Taraxacum officinale* (common dandelion), and *Acer saccharum* (sugar maple). Examples in which the species name is capitalized because it comes from the name of a person are *Opuntia Rafinesquii* (a cactus named for Rafinesque), and *Hordeum Pammeli* (a grass named for Pammel). Rafinesque was one of the earliest botanists in America and Pammel is an American botanist of our own time. Examples of specific names capitalized because they were formerly generic names are *Brassica Rapa* (turnip) and *Dicentra Cucullaria* (dutch-

man's breeches). Examples of the capitalization of Linnæan species are *Rumex Britannica* (great water dock) and *Delphinium Ajacis* (a larkspur).

In some cases a variety is distinguished from the typical species and in these cases the botanical name consists of three parts. In some books in which botanical names are used, the abbreviation "Var." is used before the variety name, examples being *Juniperus communis* Var. *montana* (a juniper), and *Aster patens* Var. *gracilis* (an aster). In other works the three names are written together, as *Mentha canadensis borealis* (a mint), and *Castilleja angustifolia hispida* (an Indian paint brush).

The person who first publishes a name for any species is known as the author of that name, and his name, usually in abbreviated form, is placed after the botanical name. Linnæus named many species and the initial L or the form Linn is common after botanical names, as is illustrated by *Quercus rubra* L. (red oak), and *Saccharum officinarum* Linn. (sugar cane). The botanical names now in use are the work of several hundred different authors. Among the familiar abbreviations following botanical names are: DC (De Candolle) a French botanist, Hook (Hooker) an English botanist, and T. and G. (Torrey and Gray), B. S. P. (Britton, Sterns, and Poggenberg), Coult (Coulter), Rydb. (Rydberg) American botanists. While the name of the author is usually used for exactness, botanical names are sometimes printed in general discussions without the name of the author.

Names of genera have originated in several different ways. Some generic names are the classical names of the plants, some are derived from words indicating properties or characteristics of the plants, some from the names of persons, some from words indicating the kinds of places in which the plants grow, and others from words indicating medicinal properties of the plants. The word *Rosa* which is the name of the genus including the numerous species of roses is the Latin word for rose. The word *Osmorhiza,* which is the name of the genus including the several species of sweet cicely, comes from two Greek words meaning "a scent" and "a

root" and alludes to the fact that the root has an odor, while the genus *Fragaria,* which includes the strawberries, is named from the fragrance of the fruit, and the genus *Rhododendron,* which includes the rhododendrons, is from the Greek for "rose-tree" in allusion to the fact that several of the species are somewhat tree-like in size and form and many of them have clusters of large showy flowers. The genus *Dicksonia,* which includes some of the ferns, is named from Dickson, an English botanist, and the genus *Harrimanella,* which includes a species of heather growing at high altitudes, is named from E. H. Harriman, an American financier. As an illustration of a genus named for the kind of place in which the plants grow the genus *Ranunculus,* named from a word meaning "a little frog" in allusion to the fact that several of the species grow where frogs abound, may be mentioned. Examples of genera named from medicinal properties are *Althæa,* named from a word meaning "to heal" in allusion to the healing properties of the flowers and leaves; *Malva,* named from a word meaning "soft" in allusion to the softening and soothing properties of parts of the plant when applied to the irritated skin; and *Belladonna,* named from two words meaning "beautiful" and "lady" in allusion to the fact that when a preparation of belladonna is put into the eyes the pupils are dilated.

Species names have likewise originated in a number of different ways. Those given in honor of persons are illustrated by *Polygonum Douglasii* (Douglas' knotweed), named for David Douglas, a Scotch botanist, and *Delphinium Treleasei* (Trelease's larkspur), named for William Trelease, an American botanist. Examples of specific names derived from the names of places are *Anemone virginica* and *Rhododendron californicum.* Specific names given in allusion to the kinds of places in which the plants grow are illustrated by *Polygonum maritimum* (a seashore knotweed) and *Ribes lacustre* (a swamp gooseberry), and the giving of specific names in allusion to the characteristics of the plant is illustrated by such botanical names as *Ranunculus parviflorus* (the small-flowered buttercup) and *Fatsia horrida* (the devil's club). Some specific names indicate the season at

which the plant blossoms. In the name *Crocus verna* the species is named from the fact that the blossoms are conspicuous in early spring. In the name *Fumaria officinalis* (common fumitory) the specific name indicates that the plant has been included in the lists of official drugs.

Suggestions for Further Reading.

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PART IV.

PLANTS IN RELATION TO THEIR ENVIRONMENT.

CHAPTER XXV.

THE CHARACTER OF ECOLOGICAL WORK.

Ecology is the study of organisms in relation to their environment. Most of its problems involve a consideration of both plants and animals, but the subject may be approached from either point of view. In this book we are concerned mainly with ecology from the botanical viewpoint. The environment with which plant ecology deals is mainly the natural one, but in many cases it has been more or less modified by man's activities, and the plant ecologist often deals especially with cultivated plants in relation to the environmental factors. Such expressions as forest ecology, crop ecology, and the ecology of the wheat field are in common use.

Plant ecology is commonly thought to have begun with the publication of a book by Warming in Denmark in 1895. This book has been translated into English and other languages and has been the starting point for much ecological work. Important ecological work had, however, been done before Warming's time, though it was not under the name of ecology. Foresters and others had done much work on plants in relation to their environment, and Warming's contribution was to organize the field and lay the foundations for a science. The earliest work on plants in relation

to their environment of which we have record was done by Theophrastus in the third century B.C. He gave considerable attention to plants growing in various habitats such as marshes, woodlands, and lakes and recorded a good deal about the general characters of plants found in these different habitats. Though the history of ecology as a science begins with Warming's book, many of the elementary ideas were in botanical literature before his time.

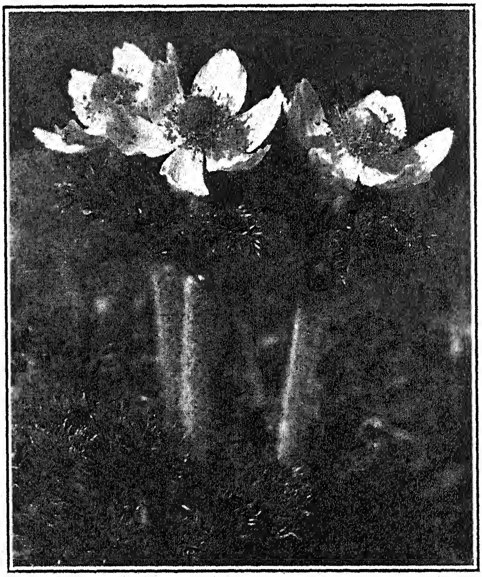

FIG. 142.—Anemone flowers on Mt. Rainier.

The study of plant ecology may begin with the consideration of either the individual plant or plants as members of plant communities. The study of the individual plant is not, however, marked off from the study of plants as associated together in communities by a distinct line; the two tend to merge and neither of them can be fully considered without giving some attention to the other.

Ecological work was at first mostly observational. The plant was examined in the field and only a general estimate was made of the quantitative factors in the environment. From this we have come to a careful study of the factors making up the environment, and have made much progress in exact measurements of these factors. For example, we now do not commonly speak of a place as being merely light or dark, but we measure the light intensity.

We have come also to a careful consideration of the interdependence of factors and of thinking of the possibility that any one factor may be also modified by another factor or factors. We also recognize that in most cases some one factor is the limiting one, and that so long as it limits the growth of plants any increase in the others cannot be effective.

Field work has also been made more definite by careful listing and mapping. Two methods of mapping vegetation are in common use—the quadrat method and the transect method. The former consists in laying out squares of suitable size and marking the corners with stakes. Quadrats from less than 10 feet up to 100 feet on each side are commonly used. The species growing in a quadrat are listed, the number of individuals of each species is recorded, and commonly a map of the quadrat is made showing the location of these. In the case of a very small quadrat a photograph may be made by supporting a downward-pointing camera above it.

Transects are of two kinds—the line transect and the belt transect. In the former a line is established across the area and the plants growing along this line are listed and mapped, while in the latter two parallel lines are established and the plants growing between them are listed and mapped.

Both of these are methods of sampling, and if the quadrats or transects are located in such a way that they are representative of the area, and if a sufficient number of quadrats or transects are used on each area, the methods are satisfactory. They may be used as a means of getting some indication of the species growing under any complex of environmental factors if the factors are carefully measured. Among the factors to be quantitatively determined are light intensity,

air temperature, evaporating power of the air, and the physical and chemical properties and water content of the soil. The use of quadrats and transects in studying plant succession is discussed later (pp. 384 and 386). Airplane photographs are very useful in showing the distribution of vegetation over larger areas. An example of this is a photograph which shows the character of the vegetation on an

FIG. 143.—Anemone plants in fruit on Mt. Rainier.

old lava flow as compared with that on the area not covered by it.

Ecology as a science has made rapid progress during the last two decades. We have accumulated many facts and have made considerable progress in systematizing these. Many principles are already plain as a result of these facts and other principles are emerging.

CHAPTER XXVI.

THE FACTORS IN THE ENVIRONMENT.

ALL the factors in an environment may be conveniently grouped under three heads: climatic, edaphic, and biotic. Among the climatic factors are light, temperature, atmospheric humidity, precipitation, and wind. The edaphic factors are those that pertain to the soil. Under biotic factors we group all the influences exercised by living things.

CLIMATIC FACTORS.

Light.—It is easy to see in the field that many plants bear a very definite relation to light intensity, some being found in full sunlight and others only in shade. Sunflowers, for instance, flourish well in the direct sun, while many ferns (Fig. 150) flourish only in shady places. The form of plants is also frequently influenced by light intensity. An extreme case of this is a potato plant growing in darkness, where it becomes long and spindling, and grows toward any feeble source of light. The effects of complete darkness in determining the form of plants is discussed under etiolation (p. 158). Many plants tend to grow taller in shade than they do in bright sunshine. The common shepherd's purse when growing in deep shade is an example of this. Water relations in both soil and air tend to be different, however, in shady places from what they are in open places, and this is commonly a factor along with light intensity in determining the form of plants.

Light intensity may be measured by various methods, none of which are entirely satisfactory. Among these are the exposure of photographic paper and noting the length of time required to change to a standard tint, as in the Clements photometer, the use of a Macbeth illuminometer in which a

Mazda lamp is used as a standard of comparison of the brightness produced, and the use of the photoelectric cell in which the electrical conductivity of a metal is changed by the light intensity and the results are read on a galvanometer or other device. The last has the advantage that it can be used for measurements under water.

Quality (wave length) of light is also an important environmental factor, but though exact experiments on its effects on the growth of plants have been made in greenhouses provided with spectral glass, less progress has been made in measuring it as a factor in the natural environment of plants.

Temperature.—Temperature is a very important factor in growth. It is usually found that any species has a definite minimum, below which it will not grow, a definite maximum, above which it will not grow, and a fairly definite optimum between these at which it will flourish best. These three are known as cardinal temperatures and they are very different in different species. Some Arctic algæ grow at a temperature only slightly above the freezing-point, while some blue-green algæ grow in hot springs where the water is so warm as to be uncomfortable to the hand.

Not only do these cardinal points vary for different species, but often in one species they may be quite different for different functions. For instance, the minimum for growth may be different in any species from the minimum for flowering, and both of these may be different from the minimum for the same species for photosynthesis.

Occasional determinations of the temperature of the air, may be made with suitable thermometers, and daily maximum and minimum air temperatures may be determined with instruments such as those used by the United States Weather Bureau. Continuous records of air temperatures running through a growing season or through a series of years may be made by thermographs.

Atmospheric Humidity.—Atmospheric humidity is also an important factor in the environment of plants. Other things being equal, a very dry atmosphere will cause more water to be evaporated from the surface of the plant, and will thus expose it to the danger of drying up; where a moist atmos-

phere would allow less evaporation, and the plant would not be in so much danger of drying up. Some plants, such as various species of cactus, flourish in the very dry air of desert regions, while some forest trees grow best where the atmosphere is foggy much of the time.

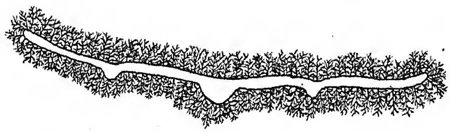

FIG. 144.—Cross-section of a mullein (*Verbascum*) leaf, showing thick, dense covering of hairs on both surfaces. (Drawn by M. W. Phifer.)

The evaporating power of the air may be measured by determining the amount of water evaporated in any given length of time from an inverted standard porous clay cup to which the water is supplied through a glass tube extending into a bottle as in the Livingston atmometer. The relative humidity of the atmosphere may be determined by the use of wet and dry bulb thermometers. The dry bulb gives the temperature of the air and the wet bulb records a lower temperature because of the evaporation of water from a piece of cloth which covers it. Tables are available for interpreting these data in terms of the amount of moisture that the air contains in proportion to the amount that it would contain at that temperature if it were completely saturated. The cog psychrometer is a convenient form of this apparatus for field use.

Precipitation.—Precipitation in the form of either rain or snow must always be considered among the environmental factors. In the case of rain, not only is the total annual rainfall important, but also its seasonal distribution. The effects of the rainfall on native vegetation, for instance, are quite different in the upper Mississippi Valley, where there is a cold winter and the rain comes in the spring and summer, from what it is in the Puget Sound region, where the winters are milder and rainy, and the summers are frequently somewhat dry, though in some portions the rainfall of these two regions is approximately the same.

Snow influences vegetation partly by its mechanical effect upon plants. In some cases plants are broken by the weight of the snow, and in others they are bent down the side of the mountain or hill so that they are permanently curved. Often the snow is a protective covering so that the cold of winter does not result so seriously as it otherwise would. Snow is also found to have an influence on the character of

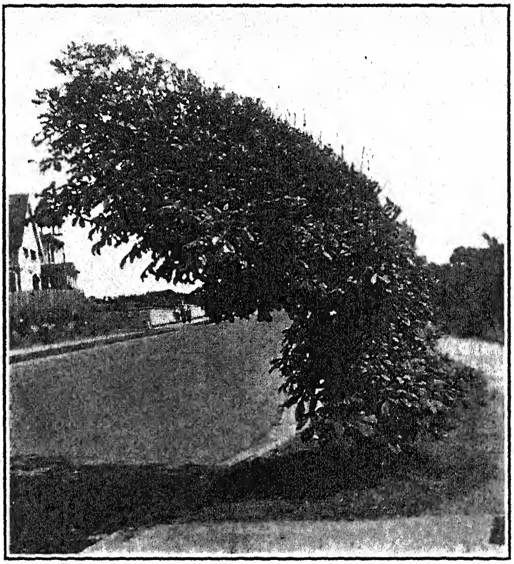

Fig. 145.—A horse-chestnut tree near the seashore in Victoria, B. C. The form of the tree is due to the prevalence of on-shore wind.

the soil during the following growing season. It also acts as a reservoir of water during the summer. Water from melting snow in the mountains provides moisture conditions suitable for the growth of plants along rivulets and around ponds near snow fields and serves to maintain the flow of some streams and the level of some lakes in lower lands. Data on rainfall and snowfall for the region can usually be

had from the nearest Weather Bureau station, or they may be measured throughout a year or more by the observer.

Wind.—Wind is very important among the environmental factors of plants. The rate of evaporation of water from plants will be greatly increased by wind, though all other factors may remain the same. If the moist air around a leaf is removed by wind and drier air takes its place the rate of transpiration will, of course, be increased. Wind may also influence the form of plants. Trees growing near the seashore (Fig. 145) are very frequently distorted and one-sided, due to the influence of wind.

Wind is also a factor in the environment of many plants because pollination is brought about by this agency, as in the firs and pines among coniferous trees, and the ragweed and other plants among the composites. Many plants are also dependent upon wind for their dispersal. Sometimes the whole plant is blown about, as in the case of the tumble weed, and sometimes it is the seeds or fruits that are borne by the wind, as in the case of the cat-tail and dandelion (Fig. 54). Wind velocity may be determined by an anemometer such as that used by the United States Weather Bureau, or by a small hand instrument. An anemometer is an instrument so constructed that the wind revolves a device consisting of four cup-shaped pieces of metal each placed on the end of a metal arm, and a dial on which the revolutions are recorded.

EDAPHIC FACTORS.

Edaphic factors may be classified as physical properties of the soil, soil water, soil atmosphere, topography, soil temperature, chemical properties of the soil, and soil organisms.

Physical Properties of the Soil.—The physical properties of the soil are determined to a considerable extent by the size and shape of the particles that compose it. On the basis of the size of the particles soils are classified as gravel, sand, silt, and clay. Little water is held by a soil composed of gravel or coarse sand, while much is held by a soil composed of silt or clay. The degree of compactness of a soil is very

important in the growth of plants in it. If a soil is very compact, particularly if the soil particles are of such a nature that they cohere closely, roots have great difficulty in penetrating into it, while they penetrate a loose soil more readily.

Many soils are composed of particles of various sizes, and the relative quantity of the particles of the different sizes may be readily determined by separating them on a nest of sieves. A nest of five sieves, the coarsest having 20 meshes to the inch, the finest 100 meshes, and the intermediate ones 80, 60, and 40 is often used. The finest one fits into the top of a pan, each of the others fits into the top of the one below it and a cover is provided for the upper one. These are arranged in order with the coarsest one at the top, a soil sample is placed on the top one and the whole nest is shaken. Some of the particles remain on each sieve while the finest ones pass through into the pan. If an exact determination is desired each portion of the soil may then be weighed.

The relative number of particles of the various sizes may also be determined readily by shaking a soil sample in water in a fruit jar. When the jar is allowed to stand after shaking, the coarsest particles form a layer at the bottom and the others form layers above this, while the very small ones remain suspended for some time in the water.

Soil Water and Soil Atmosphere.—The amount of water in the soil is important not only as a supply for the plant but because a soil which contains all of the soil water it can hold will contain no air. Field observations give general indications of the amount of water in the soil, and exact determinations may be made by weighing soil samples before and after drying.

The water present in soil is, of course, not pure water but is a complex solution of the various organic and inorganic substances with which it has come in contact, and all of these constituents of the solution may have their influence in one way or another on the plants. Unless a soil is completely saturated the spaces among its particles will be occupied by a soil atmosphere and the relative amounts of nitrogen, oxygen, carbon dioxide and possibly other gases have much

to do with the growing conditions for plants. In general the soil atmosphere is likely to contain more carbon dioxide and less oxygen than is usually present in air. This is especially true where much organic matter is present. The soil atmosphere of garden soils contains as much as 7 per cent carbon dioxide and that of soils containing sewage as much as 10 per cent. The concentration of carbon dioxide in the soil atmosphere around the roots of growing plants has been found to be from 13 to 21 per cent. These concentrations are in striking contrast with those of ordinary air, where it is from 0.03 to 0.04 per cent. It has been found by experiment that high concentrations of carbon dioxide are actually injurious to growing plants. The growth of elm trees is retarded by 2 to 5 per cent and various other plants are injured by concentrations varying from 2 to 20 per cent.

Oxygen has been found deficient in soils that contain much organic matter. Manured rice fields sometimes have no oxygen in the soil atmosphere and it is often as low as 6 per cent. In experimental work it was found that the entire absence of oxygen caused death in all plants tried. It seems evident that the microörganisms in soils containing large amounts of organic matter are a large factor in the increase of carbon dioxide and the decrease of oxygen.

Marsh gas (methane, CH_4) has been found in the soil atmosphere of cropped and manured rice plots and also in solution in the water in very wet bog soils. Such gases as are soluble in water may in all cases be present in the soil solution as well as in the soil atmosphere.

Topography.—The topography of any area is very important in the growth of plants since the flat portions will usually have poor drainage while sloping portions will be better drained. Changes in topography produced by wind and water are a large factor, often the limiting one, in the growth of plants. The movements of sand dunes are an example of the former, and the laying down of soil on the flood plain of a river is an example of the latter.

Sand dunes (Fig. 146) are common in certain portions of the United States, notably at the southern end of Lake Michigan and along the Pacific coast in Washington and Oregon.

An active dune is a hill of sand with a gentle slope on the windward side and a steep slope on the lee side. Sand is carried up the gentle slope and deposited at the top of the steep one. Frequently the movement of the sand is so continuous that no vegetation at all gets started. Often, however, plants with vigorous rhizomes do get a start, and thus

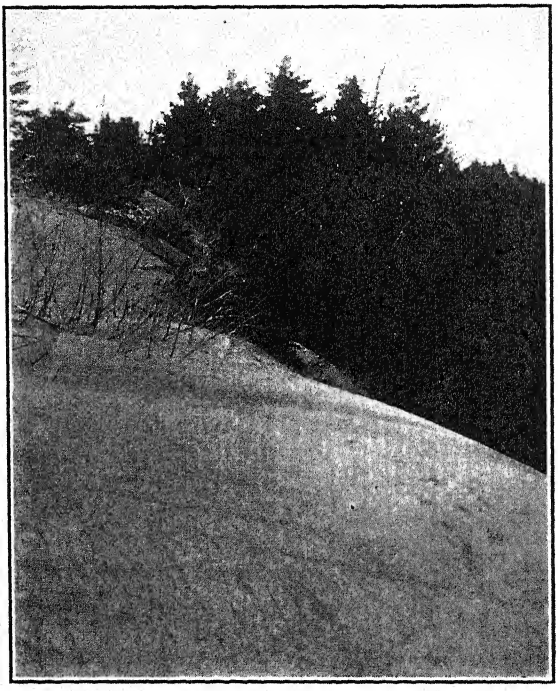

Fig. 146.—An Oregon sand dune encroaching on a forest.

bind the sand in certain areas and interfere with its movement. In many places these dunes overwhelm forests and kill them completely as is seen in the case of forests in the dunes of western Washington and Oregon (Fig. 146) and northern Indiana. Lakes and ponds are often formed in depressions among dunes in places where movement of the

sand has stopped, and water-lilies and other plants flourish in these. Often these lakes are filled when the dunes again begin to travel. Very old dunes may become quiet enough so that the ordinary plants of the region grow on them and forests on old dunes are not uncommon. Dune areas have so many striking features that a visit to a dune region is well worth while for any one interested in Nature. Further information about them may be found in the books listed at the end of this chapter.

Soils laid down by the overflow of rivers are common on flood plains. Soil particles carried in suspension by the water while it is in motion settle out when it becomes quiet and a layer of soil is thus deposited. This may bury the low plants which have grown on the area so deep as to kill them and provide a soil in which a new plant community will flourish. Many seeds are brought in by water and the presence of these seeds and the changed soil conditions may result in striking changes in vegetation as a result of occasional floods. The establishment of willow thickets on areas which were formerly occupied by meadows of native grasses has often been observed in certain portions of the drainage basin of the Missouri river.

Soil Temperature.—Soil temperature is a large factor in the growth of plants. Certain plants are characteristic of cold soils and others of warmer soils. Occasional measurements of soil temperatures may be made with a soil thermometer, and a complete record for a year may be made with a soil thermograph. This instrument consists of a metal pipe which can be buried in the soil at any depth, and a flexible metal tube connecting this with the recording instrument. The pipe and tube are filled with some suitable liquid and the expansion and contraction of this liquid govern the position of the pen which records the temperatures by a continuous line on paper placed on a drum revolved by clock-work.

Chemical Properties of the Soil.—The chemical properties of the soil have to do largely with the nutrients present in it. The necessary salts for the growth of plants, such, for example, as the salts of potassium, calcium and iron, are

frequently present in the form of chlorides, nitrates, and sulphates.

The chemical reaction of the soil is also an important factor in the growth and development of plants. Whether the soil is acid, alkaline or neutral often determines what plants can flourish in it and what ones cannot. These conditions can be expressed exactly in terms of hydrogen ion concentration and the expression pH is used for this purpose. A neutral solution has pH 7, an acid solution less than 7, and an alkaline solution more than 7. The complete determination of the chemical properties of a soil requires, of course, a quantitative determination of its constituents, and this must be made in a well-equipped laboratory by an experienced chemist. A fairly good indication of the acidity or alkalinity of a soil can be made in the field with an inexpensive hydrogen ion set, but it is desirable to make more exact determinations in the laboratory.

Soil Organisms.—Soil organisms influence both the physical and the chemical properties of the soil and they are discussed under biotic factors (p. 352).

BIOTIC FACTORS.

Among the biotic factors are other plants, animals and man, man's activities being so extensive and various that it seems wise to discuss them separately from the activities of animals.

Other Plants.—Among the ways in which plants may influence the growth of other plants is by shading them, as for example the ferns that grow in the shade of a forest (Fig. 150); also the humus produced by the decay of former plants is frequently a factor.

Living microörganisms in soils are often numerous and must always be considered in estimating the soil as a medium for plant growth. Bacteria, molds, and other fungi are common; protozoans are frequently found; and some algæ occur. The respiratory processes of all of these organisms influence the relative amounts of carbon dioxide and oxygen in

the soil, and many of them cause decay or putrefaction of the organic matter of the soil. Many kinds of bacteria exist free in the soil, but at least one species flourishes in symbiotic relation (see p. 366) with the roots of living plants. This species grows in root tubercles of clover and other plants of the legume family. The bacteria here are a factor in the life of the clover, and the clover is, of course, an important factor in the life of the bacteria. These bacteria differ from most organisms in being able to use the uncombined nitrogen of the air. They combine this nitrogen with other elements in forms in which it can be used by the plants on which they flourish or it may remain in the soil and be used by those which grow there later. Legume crops such as clovers are commonly used in crop rotation to increase the amount of nitrogen in the soil. Care must be taken, however, to be sure that the bacteria are present since legume crops may grow without the bacteria, and in that case they would not be effective.

Bacteria that are able to take the free nitrogen of the air and combine it into the complex substances that make up their cells also exist free in the soil independent of the roots of plants, and these are often quite as important as those that form symbiotic relations with roots. Nitrogen fixation is only one of the many activities of bacteria in soils. Many different kinds of bacteria are present, and some of them build up certain compounds while others break them down.

The presence of microörganisms in the soil is discovered in part by direct microscopic examination and in part by placing samples of the soil in appropriate sterilized media and determining the organisms that grow there.

Biotic factors are strikingly illustrated by cases in which one plant grows on another and derives nourishment from it. An organism dependent on another in this way is called a parasite, and parasitism is discussed on p. 364.

Animals.—Animals influence plants in many ways. One of the ways in which they are beneficial is by the pollination of flowers. Cross-pollination of red clover is brought about by bumble bees, and of sage by various insects. The relation between the form and color of flowers and the visits

of insects to them which result in pollination is a very intricate and interesting one.

In a few cases plants posses means of getting animal food. Among these may be mentioned the pitcher plants (Fig. 149), in which various kinds of insects get into the pitchers and are finally used as food by the plant. Another case is the butterwort, in which the insects are caught on the surface of the sticky leaves and are digested after the margin of the leaf is rolled inward. The sundew, a common plant of sphagnum bogs, digests insects which become stuck fast in the drops of liquid secreted at the tips of the hairs. The hairs bend over and press the insect down upon the leaf and then become erect again after the insect is digested.

Seed dispersal by animals is common and is thus an important phase of the biotic relationship. Burs, such as cocklebburs and sand-burs, are frequently caught in the hair of animals and thus carried to new locations. In some cases berries are eaten by animals, and when the pulp is digested the seeds are not affected by the digestive tract and are thus scattered.

Man's Activities.—Man's activities have influenced the character and distribution of plants very greatly. He has developed cultivated plants from wild ones, this having been brought about in many cases not only by selection but also by cross-breeding (see p. 316) and these he has distributed throughout the world as suits his convenience.

By breaking the prairie and by removing the forest he opens the way for many weeds to flourish where they otherwise would not have had an opportunity. Other well-known ways in which man influences the distribution of plants are the incidental scattering of seeds in the shipment of grains, hay and other plant products, and the killing out of certain plants by the pasturing of domestic animals.

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CHAPTER XXVII.

INDIVIDUAL PLANTS IN RELATION TO THEIR ENVIRONMENT.

Plants are commonly classified on the basis of their relation to their environment. Such a classification obviously has no relation to classifications made on a morphological or taxonomic basis and species which are quite unrelated on this basis may come in the same ecological class. A very useful classification is that based on the relation to water, and plants are thus divided into four classes. Hydrophytes are plants growing where water is abundant, xerophytes those growing where water is scarce, mesophytes those growing where there is a medium supply of water, and halophytes those growing where the soil water contains much salt.

These four words refer to plants and since ecology deals with both plants and animals it is desirable to have adjectives that will characterize either the water conditions of the habitat or the general character of the organisms found in them. The adjectives hydric, xeric, mesic, and halic are used for this purpose. Hydric is used to characterize a habitat in which water is abundant or an organism commonly occurring in such a habitat. Xeric, mesic, and halic are similarly used in reference to either the habitat or the plants and animals characteristic of the habitat.

HYDROPHYTES.

Hydrophytes differ a good deal in the positions that their organs occupy with relation to water. They may be conveniently grouped under four heads: (1) those that have their vegetative parts completely submerged; (2) those that are submerged except that their leaves float; (3) those that

have the base in water and the upper parts in air; (4) those that are free-floating.

Plants that have their vegetative parts submerged commonly have the flowers borne on special stalks extending above the surface of the water, and in some a few leaves appear above the surface of the water on the flowering portion. Three common examples of this class of hydrophytes are water milfoil (*Myriophyllum*), waterweed (*Elodea*), and bladderwort (*Utricularia*).

Water milfoil is a perennial plant represented by several species in various parts of the United States and other countries. The leaves are crowded and the ones under water are pinnately divided into numerous slender parts. The flowers and a few leaves are usually borne above the surface of the water. The waterweed is a slender perennial herb with small, undivided, veinless leaves. The pistillate flowers are borne at the surface of the water and the staminate flowers break away from the plant and float so that the pollen when discharged reaches the stigmas. There are several species of bladderwort some of which float free while others are rooted in the mud under shallow, quiet water. A very common one (*U. vulgaris*) is widely distributed in North America and Europe. Its leaves consists of many divisions so fine as to be almost thread-like. They bear small bladder-like bodies in which small animals are trapped. Its flowers are borne above the surface of the water. All three of the plants described are common in shallow water in the margins of ponds and slow-moving streams. Some of the pondweeds (*Potamogeton*) have two kinds of leaves, one floating on the surface of the water and the other borne on the submerged stem. Many submerged plants have special vegetative reproductive bodies which lie dormant in the mud at the bottom of the pond or lake during the winter and produce new plants in the spring.

Some hydrophytes have all of their vegetative parts submerged except the leaf blades, which float on the surface of the water. The common water-shield (*Brasenia*) has rhizomes growing in the mud and has floating leaf blades borne on long slender petioles. The submerged parts are

covered with a thick coating of tough, transparent, jelly-like material. The flowers are small and purplish. The water-lilies (*Nymphæa* and *Castalia*) mostly have floating leaf blades and very slender petioles, though some have stouter petioles, which in most cases support the leaf blade above the surface of the water.

A good many hydrophytes have their roots either in water or mud, while the stem, leaves, and flowers are borne in the air. Among these are the arrowhead (*Sagittaria*), the bulrushes (*Scirpus*), and the mare's tail (*Hippuris*). A common species of arrowhead (*S. latifolia*) is readily recognized by its large leaves with arrow-shaped blades. It is common in the margins of lakes and ponds in many parts of the United States. The bulrushes are widely distributed and grow abundantly in marshes and shallow lakes. Mare's tail has jointed stems which slightly resemble those of the scouring rush. Its rhizomes commonly grow in the water instead of in the mud.

Some plants float free on the surface of the water. Considerable areas of fresh water are often covered with duckweed (*Lemna*). The individual plants are usually less than ½ inch across and consist mostly of a thallus-like body, which has two or more leaves on the surface of the water, and a single root which dangles in the water. One species of liverwort also floats on the surface of the water and often covers considerable areas in quiet ponds and lakes. Another plant which floats on the water is the water hyacinth (*Eichhornia*) which multiplies very rapidly by vegetative means and has an enlarged portion with spongy tissue in it, which enables the plant to float. The roots of this plant sometimes grow into the soil in shallow water and thus anchor the plant, although the upper parts rest on the surface of the water.

Some plants are capable of growing either in water or out of it. Examples of this group are water-celery (*Œnanthe*), some species of grass, and at least one species of knotweed (*Polygonum*).

Though no exact statements can be made about the form and structure of hydric plants that will apply to all of them,

certain features are rather common. They usually have large air spaces in their organs (Fig. 147) and in many cases these air spaces are really in the form of channels through which air may readily diffuse for some distance lengthwise in the plant without passing through any membranes at all.

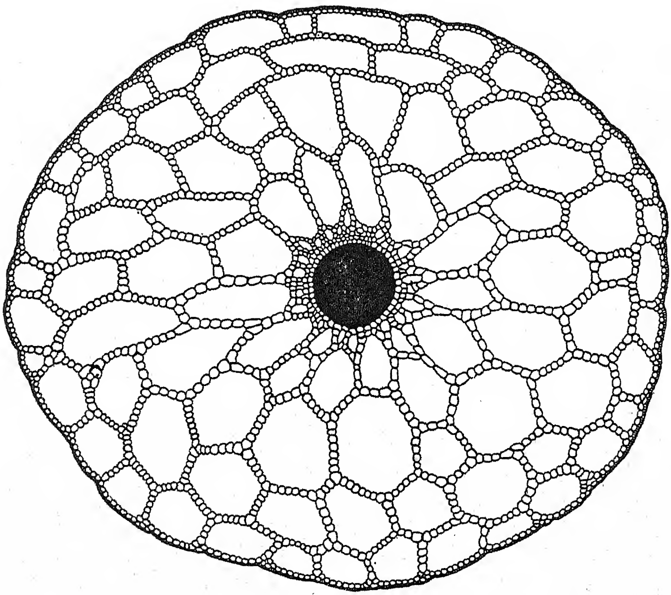

FIG. 147.—Cross-section of a stem of mare's tail (*Hippuris vulgaris*). The vascular tissues are confined to the darkened circle at the center. The air spaces are separated by partitions one cell thick. (Drawn by M. W. Phifer.)

The root system of hydrophytes is usually small and poorly developed. This seems, like many of the other facts about their form and structure, to correlate with their growth in water where the opportunities for absorption are very large. The aërating tissues we may correlate with the fact that the gases are not abundant under the water, and that at least in those that have some of their parts in the air

the gases are diffused from the top of the plant to the lower part of the stem and to the roots.

The amount of vascular tissue in water plants is also greatly reduced (Fig. 147). At least in the case of submerged plants this seems to correlate with the fact that water can probably be taken in at almost any point on the plant. In submerged plants there is very little hard tissue. The growth in a relatively dense medium like water seems to be correlated with the lack of necessity for strengthening tissues.

The epidermis of the submerged portions of plants is usually much modified. In fact, where the plant has chlorophyll in the cells of its outer layer and there are no stomates, we sometimes speak of the condition as the one in which there is no epidermis present. Many submerged leaves are either very narrow, or else they are dissected into narrow segments. This fact we may associate with the idea of the movement of water being more likely to do mechanical damage to large leaves.

XEROPHYTES.

Xerophytes are especially characteristic of desert regions. Among those showing striking xeric characters of form and structure are the various kinds of cactus found in the deserts of certain portions of southwestern United States. They are mostly fleshy, leafless plants with green stems and many of them have spines or prickles. The giant cactus (Fig. 151) has columnar, fluted stems which contain so much water that the plant may live for several years on the water thus stored. The loss of water is slow because of the thick cuticle and the sunken stomates, and is regulated to a certain extent by the shrinking of the stem as its water content becomes less so that the ridges come closer together and its surface is thus less exposed. This plant also contains much colloidal material which holds water tenaciously.

It is impossible to state any group of characters of form and structure which will be found in all xerophytes but certain characters are very general. They are likely to have

large root systems, especially when they grow in a dry, sandy soil, which offers very little mechanical difficulty in the penetration of the roots. It has been found when investigating the roots of one species of hawkweed (*Hieracium Scouleri*) that their roots commonly penetrate to a depth of over 6 feet in the soil.

This large root development is interesting in comparison with the small development of the aërial portions of the plant. The stem is not usually over 2 feet tall and though the basal leaves are fairly large the stem leaves are much reduced. The structure of the leaves, too, is such as to make the evaporation of water from them rather slow. This plant is well fitted to grow in dry places, and is a good illustration of the general principle that xerophytes make economical use of water. This economical use is accomplished by keeping a balance between water intake and water loss. By one means or another they absorb considerable water in spite of the scant supply and they also lose comparatively little by evaporation.

Some plants growing in regions where there is very little rain have thick roots which store water so that the plants can remain alive through several months during which there is no rain at all. The intisy tree (*Euphorbia intisy*) of southern Madagascar is an example of this.

Certain modifications of the leaves are also characteristic of many xerophytes. A very common condition is that in which the leaves are very much reduced, as in the cacti and other desert plants; or are very thick, as in stonecrop (*Sedum*). A good many xerophytes have rolled leaves. In the case of the crowberry (*Empetrum*) which grows in northern regions and on some mountains in temperate regions, the edges of the leaf are inrolled until they touch at the back, so that the ventral surface of the leaf is not directly exposed to the air at all. Other leaves, such as those of some of the grasses (*Spartina*), roll and unroll, depending upon whether the conditions surrounding the plant are moist or extremely dry. In some leaves the stomates are also sunken beneath the surface so that evaporation from them is slower than it would be if they were at the surface. Other xeric leaves have a

large development of palisade tissue on both sides of the leaf, where most mesic leaves would have a similar development of palisade tissue at the upper surface only, with a large amount of spongy parenchyma next to the lower surface. The leaves of many plants growing in dry places also have thick cuticle. This is found in many broad-leaved evergreens, such as the rhododendron and some of the laurels. Xeric leaves are also likely, in some cases, to have hard tissues within the leaf, such, for instance, as is found in *Banksia*. Many xerophytes have a more or less dense growth of hair on the surface, as compared with the very smooth surface of mesophytes or hydrophytes. This is illustrated by the common roadside mullein (Fig. 144) and by the alpine thistle.

The leaves of some xeric plants have means of storing water either in their tissues or in cavities connected with the leaf into which atmospheric moisture, condensed on the leaf, runs. Colorless tissues in the leaf blades, such as those found in the rubber plant (*Ficus elastica*) and the gumweed (*Grindelia*), illustrate the former, and the large cavity at the base of each leaf of the travelers' tree (*Ravenala*) of Madagascar, illustrates the latter.

In addition to all of the above structural characters it has been found that many xeric plants contain a large amount of more or less mucilaginous or gummy material, which is in a colloidal state. Material of this kind imbibes water in considerable quantities and holds it with great force. Such a condition as this is found in many of the cacti, where enormous pressure fails to get out all of the water in them. Although the first of the water may press out rather easily, the difficulty of pressing it out becomes greater and greater as the water in them decreases. Probably the water-holding power of this colloidal material aids a good deal in keeping down transpiration in desert plants.

MESOPHYTES.

Mesophytes are plants whose relation to water is between the two extremes seen in hydrophytes and xerophytes. They

are the ordinary plants of everyday life which grow with a moderate water supply. Among the plants which constitute this class are the common buttercups and trilliums (Fig. 1), and most of our common garden and crop plants such as peas, beans, oats, and corn.

Many herbaceous mesophytes are annuals and exist during the winter as seeds. Only the underground portions of herbaceous perennials such as the trilliums and some of the buttercups live during the winter, and herbaceous mesophytes thus have aërial portions only during the growing season. Most deciduous trees and shrubs such as willows, maples, alders, and roses are mesophytes and the case with them is somewhat different from that of herbaceous mesophytes. They change from their summer condition in which they absorb water readily and transpire it freely to the winter condition in which they neither absorb nor lose water in any considerable quantities.

Certain features of the roots and leaves of mesophytes are so common that they may be mentioned as characteristic of the group. They have fairly large root systems, usually much branched, and root hairs are abundant. The leaves are relatively large and have stomates on both surfaces except in trees, where they are frequently on the lower surface only. They usually have a plentiful supply of chlorophyll and in this they contrast with xerophytes, many of which show a pale-green color.

HALOPHYTES.

Halophytes grow in salt marshes or other places where there is a high concentration of dissolved substances in the soil water. The soil water thus has high osmotic pressure (see p. 135) and the juices of the plants usually have high osmotic pressure also. Glasswort (*Salicornia*) is a fleshy, leafless plant common in marshes into which sea water penetrates at least at high tide. The osmotic pressure of its juice is commonly over 30 atmospheres and has been found to be as high as 45. The osmotic pressure of sea water under ordinary conditions is about 20 atmospheres. The high

osmotic pressure of the juice of plants characteristic of halic conditions contrasts sharply with the lower osmotic pressure of the juice of plants characteristic of mesic conditions.

Certain similarities between glasswort (a halophyte) and cactus (a xerophyte) may be observed. Both are practically leafless, both are fleshy, and both develop colloids (see p. 24) in their cells which hold water and thus tend to make transpiration slower. Other salt-marsh plants showing xeric characters are arrow grass (*Triglochin maritima*), which has fleshy leaves, and salt grass (*Distichlis spicata*) which is pale in color and has inrolled leaves.

SYMBIOSIS.

Several ecological classes are based on other factors than water. These factors are largely biotic and most of them can be grouped under symbiosis. This term includes all cases in which organisms of different species live together in a definite relationship, whether this is to their mutual advantage or not. Organisms growing together in such a relationship are called symbionts. Symbiosis may exist between plants and animals as well as between two species of plants or two species of animals. In this book we are concerned with those cases in which one of the symbionts is a plant. Some of the cases considered under biotic factors (pp. 352 and 353) are examples of symbiosis. Only a few of the many kinds of symbiosis can be discussed here.

Parasites.—Parasitic plants are those that live on other living organisms (mostly plants) and derive food or raw materials from them. The living organism on which a parasite grows is called its host. A common case of parasitism is the growth of dodder (*Cuscuta*) on willows, goldenrods, alfalfa, and other plants. Dodder is a slender, threadlike plant that twines about its host and sends absorptive processes called haustoria into its tissues. This plant is leafless and has a yellowish or orange color. It has no chlorophyll and is thus unable to manufacture its own carbohydrate food. Its seeds germinate on the ground and it forms a temporary connection with the soil until its stem

attaches itself to the host. There are many species of dodder and they are widely distributed in the United States and other countries. Some of them are very injurious to such crops as flax, clovers, and alfalfa. Their seeds are very small and thus often escape notice among the seeds of the host plants. Great care is now taken to remove all dodder seeds from those of crop plants, and the fight against this pest has been a fairly successful one. It is abundant, however, on wild plants in many places and large patches of it are common on *Salicornia* in salt marshes and it is also abundant on various plants of the composite family and it is frequently found on willows and some other woody plants.

Various species of mistletoe of two genera (*Phoradendron* and *Arceuthobium*) are common on trees. They are dependent on the host for water but have more or less chlorophyll and are able to manufacture at least a part of their food. They are found on oaks and other broad-leaf deciduous trees and also on firs, hemlocks and other coniferous trees. Some of the mistletoes have sticky seeds and explosive fruits and the seeds thrown by their fruits readily adhere to the bark of the hosts and germinate there. The seeds of some species are also distributed by birds. When birds eat the fruits the seeds stick to their bills and are thus carried by them to other trees where they are wiped off on the bark. Mistletoes are often very injurious to trees and are thus of some economic importance. They do great injury to some oaks and often cause excessive growth of small crowded branches on some conifers. These growths are called "witches' brooms" and are conspicuous on some firs and other trees. Not all witches' brooms, however, are caused by mistletoes. They may be due to fungi or other organisms.

Root parasites are also common. Since the attachment to the host is underground and the aërial portion of the parasite comes from the soil at a little distance from the stem of the host the parasitic relation is not at once apparent. Examples of root parasites are the plants called pine drops (*Pterospora*) which are commonly parasitic on the roots of conifers, and several species of broom-rape (*Orobanche*) which are parasitic on the roots of various plants. *Pterospora*

is a tall reddish-purple plant with scattered scale-like leaves, found in many parts of the United States. The plants die after the flowers are mature and their dead stems, often 2 or 3 feet tall, are conspicuous in open coniferous forests.

The parasitic species of broom-rape occur on the roots of several species of plants of the composite family and also on hemp, tobacco, and salal. It is parasitic on lateral roots and often occurs several feet from the stem of the host. All of the plant except the flowering shoot is underground. This flowering shoot is very short and its leaves are scale-like and usually brownish or whitish.

Reciprocal Symbiosis.—Cases in which two species live together to their mutual advantage are called reciprocal symbiosis as distinguished from antagonistic symbiosis, which is illustrated by parasitism. The lichens furnish a striking example of reciprocal symbiosis. Their structure and methods of reproduction have already been described (pp. 234 and 236) and the mutual advantages of the association of the alga and the fungus which form the body of a lichen have been discussed. A unique feature of this association is the formation of the special vegetative reproductive bodies (soredia) which include both the alga and the fungus and thus provide for the continuance of the symbiotic relationship in the plants produced by them. Another example of reciprocal symbiosis is the relation between the bacteria in root tubercles (p. 353) and the plants on whose roots the tubercles occur.

Saprophytes.—In the cases of symbiosis described above, the relation is in part a nutritive one. Saprophytes may be discussed here, though saprophytism is not a case of symbiosis. Saprophytes are plants that get their food from dead organic matter, and some of them can live either as saprophytes or parasites. The bracket fungi and some bacteria are examples. A bracket fungus may grow as a parasite on a living tree, but continue to live as a saprophyte on dead organic matter after the tree is killed. It often grows on dead stumps (Fig. 99) where its mycelium (see p. 228) may have been in the living tree as a parasite or may have entered

the stump as a saprophyte after the tree was cut. The typhoid bacillus is primarily a parasite in the human body, but it lives also as a saprophyte in water and in milk and

FIG. 148.—Indian pipe (*Monotropa uniflora*), a saprophyte, growing in rich woods.

other foods. The tetanus bacillus is primarily a saprophyte living in soil but is incidentally a parasite when introduced into the human body through a wound.

Among the seed plants that live as saprophytes are the Indian pipe (*Monotropa*), the coral root (*Corallorrhiza*), and the snow orchid (*Cephalanthera austinæ*) (Fig. 134). The Indian

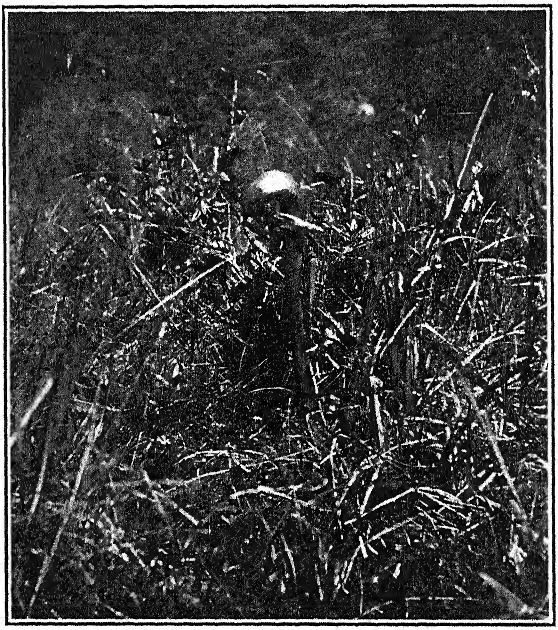

FIG. 149.—A pitcher plant (*Darlingtonia californica*), growing in a *Sphagnum bog.*

pipe (Fig. 148) is a whitish plant of waxy appearance occuring in clusters in rich woods where decaying organic matter is abundant. It is entirely devoid of chlorophyll and is therefore unable to form its own carbohydrate food. Its leaves are merely small scales.

The various species of coral root are herbs somewhat

similar to the Indian pipe in form, but having a reddish-brown or yellowish color. They occur on decaying organic matter in the soil of groves and forests in many parts of the United States and other countries. The snow orchid is a rare plant found in western United States. It is waxy white and practically leafless. It is found only in deep woods (Fig. 150).

Social Symbiosis.—Plants often show symbiotic relationships, in which no nutrition is involved. These cases are called social symbiosis. Many plants are rooted in the soil and have long stems which climb by one means or another. Such plants are called lianas, and where the support is another plant the relation is a symbiotic one. Some cultivated plants climb on supports provided for them, and in citing examples, such plants will be included along with those that climb on other plants. A common method of climbing is by twining around the support. This is seen in such herbs as hops, morning glories and bindweeds, and in such woody plants as bittersweet, and honeysuckles. Woody twiners are especially abundant in tropical forests where they form a conspicuous feature of the vegetation.

Many plants such as grapes, sweet peas and some vetches cling to their supports by means of tendrils, while others such as the Virginia creeper hold to trees or other supports by means of aërial roots. Climbing plants get their leaves into positions advantageous for light without developing strong stems, but where supports are not available they are at a great disadvantage. In tropical forests the festoons of lianas are sometimes so dense on the trees that some fail to find support and grow in dense masses on the ground.

Some plants are entirely dependent on other plants for support and are not rooted in the soil at all. Plants growing in this way but not deriving nourishment from the plants on which they are supported are called epiphytes. Some lichens have such symbiotic relations with trees. Long thready ones form moss-like festoons pendant from the branches of trees in damp forests, and foliose ones often form dense growths on the branches of forest trees and fruit trees

in moist regions. Many ferns such as the licorice fern often grow on trees also. Their rhizomes are commonly embedded in a dense growth of mosses or leafy liverworts and these as well as the ferns are epiphytes. It is probable that in such cases the epiphytic relation is to a certain extent also saprophytic, since no doubt there is some decay of the bark of the tree or of the older parts of the mosses and liverworts so that some organic material may be absorbed.

An excellent discussion of symbiosis is presented by W. B. McDougall in the work included in the list at the end of Chapter XXVI.

CHAPTER XXVIII.

PLANT COMMUNITIES.

PLANTS naturally associate themselves into communities, large and small. All of the factors of the environment may have their influence in determining what kind of community will occupy any given area, but in many cases some one factor is the limiting one. Climate often determines the general nature of the plant community over a large area. One illustration of this is the grassland community occupying much of the portion of the United States, Northern Mexico and Southern Canada between 95 and 110 degrees west longitude. Another is the Arctic tundra, which covers the extreme northern portion of North America and is characterized by sedges and lichens and some very small shrubby plants.

The nature of many smaller communities is determined largely by water, though of course other factors operate. Swamps, prairies, deciduous forests, coniferous forests, and deserts are illustrations.

SWAMPS.

Swamps are present along the shallow, muddy margins of ponds and lakes in many parts of the United States. The water table is often at the surface of the soil, though it usually varies during the year and may be sometimes above the surface of the soil and sometimes below it. The swamp community, however, usually extends into the shallow margin of the pond or lake. Plants characteristic of swamps are cat-tail (*Typha*), bulrushes (*Scirpus*), the reed (*Phragmites*), and bur-reeds (*Sparganium*). The bulrushes usually dominate on the side of the swamp toward the lake, often forming a pure stand in water 4 feet or more deep, while the reed is

usually most abundant on the shore side. The plants of this community develop a dense growth of horizontal rhizomes in the substratum, and this gives firm support to the tall aërial portions, which also form dense growths.

PRAIRIES.

Prairies dominated by tall grasses were best developed in western Iowa, eastern Nebraska, and the region immediately north and south. These have been largely destroyed as the lands have been brought into cultivation but in some places they have been left undisturbed. The grasses make a rank growth and are well rooted, forming tough sod. Examples of these grasses are the blue-joint (*Agropyron*) and porcupine-grass (*Stipa spartea*). These prairies furnished the wild hay cut by the early settlers. Many other plants flourish in these prairies and the competition between these and the grasses for space, water, and light is intense. The appearance of these prairies varies with the advance of the seasons and the changes in the floral covering. Among the spring plants are the ground plum (*Astragalus caryocarpus*), false indigo (*Baptisia bracteata*), a phlox (*Phlox pilosa*), blue-eyed grass (*Sisyrinchium angustifolium*), and the blue violets (*Viola*). A large sunflower is common in summer and the lead plant (*Amorpha canescens*), and wild licorice (*Glycyrrhiza lepidota*) are also seen. The autumn brings an abundance of asters (*Aster*) and goldenrods (*Solidago*). Prairies of this type occur in regions having a continental climate with rather long cold winters and moderate rainfall, abundant in spring but continuing during the summer. The term continental climate is used with reference to the climate of regions so far from the coast as not to be influenced by winds from the ocean. Such a climate usually has a rather wide range of temperature, both annual and diurnal.

DECIDUOUS FORESTS.

Deciduous forests are common in regions of temperate climate. Here the trees grow vigorously during the favorable

conditions of temperature, moisture, and light in spring and summer, and are leafless and dormant during the winter when these conditions are less favorable. In the United States they have been abundant in the portion east of the Mississippi river but in some places they have now been removed or much modified. The beech-maple forest which has developed so well in the northeastern portion of this region may be taken as an example of a deciduous forest.

This forest is in the main dominated by a beech (*Fagus grandiflora*) and the sugar maple (*Acer saccharum*), though oaks (*Quercus*), the basswood (*Tilia americana*) and the yellow birch (*Betula lutea*) are abundant. Other trees such as elm and black walnut are less characteristic but commonly present. Many smaller trees are common; the ironwood (*Ostrya*), the flowering dogwood (*Cornus florida*), and the hawthornes (*Cratægus*) are familiar examples. Deciduous shrubs are also common. Among these are the June-berry (*Amelanchier*), the prickly ash (*Zanthoxylum*), and the poison ivy (*Rhus toxicodendron*).

Herbaceous plants are abundant on the forest floor under these trees and shrubs. They are conveniently grouped according to the season at which they show their best development. In spring, when light conditions are favorable because the trees and shrubs are leafless, many perennial herbs which have stored an abundance of food in their underground parts grow vigorously and form an attractive feature of these forests. Among them are the bloodroot (*Sanguinaria*), the Indian turnip (*Arisæma*), the trilliums (*Trillium*), and the columbine (*Aquilegia*). The summer flora of this forest floor includes a number of herbs. The sanicle (*Sanicula*) is an example. In autumn a few asters and goldenrods are found.

CONIFEROUS FORESTS.

Coniferous forests, commonly called evergreen forests, often flourish where the summer rainfall is a little less and the winters colder than in the regions characterized by deciduous forests. Coniferous forests growing under such

conditions formerly covered large areas in the New England states and in northern Michigan, Wisconsin and Minnesota, but they have now been largely destroyed by logging. Coniferous forests also occupied considerable areas in southeastern United States, where the climatic conditions are different from those mentioned, due to favorable combinations of soil factors with climatic factors. Considerable

FIG. 150.—Ravine vegetation in a partially cleared coniferous forest. Sword fern and snow orchid in the foreground. Near Chico, Wash. (Photograph by J. B. Flett.)

areas of virgin coniferous forests still remain in western United States in California (Fig. 125), Oregon, Washington, Idaho and Montana and also in western Canada, though large areas in both countries have been logged over so that the character of the forests has been much changed. Near the coast many such forests often flourish in regions where the winters are mild and rainy, while the summers are relatively cool and dry (Fig. 150).

A coniferous forest usually has one or two dominant evergreen conifers and several others less abundant. Deciduous trees are sometimes mixed with these. Under the trees are shrubs; frequently some deciduous and some evergreen. Ferns and herbaceous flowering plants are common on the forest floor (Fig. 150).

A Douglas fir forest such as flourishes in the Puget Sound region in northwestern United States is a good example of a coniferous forest. Much of this forest reaches its best development on soil that was laid down long ago by glaciers and consists of clay with a liberal mixture of stones of various sizes. The forest developing on such a soil at moderate elevations (less than 1000 feet) where drainage is good is dominated by the Douglas fir (frontispiece), with which occur the western hemlock (*Tsuga heterophylla*) and the giant cedar (*Thuja plicata*). Some white fir (*Abies grandis*) occurs and the western white pine (*Pinus monticola*) is found especially on hills where the soil is gravelly. The western yew (*Taxus brevifolia*) is an occasional tree, never abundant. Other conifers occur in this forest under different conditions of soil and drainage and at increasing elevations.

Deciduous trees are fairly common but are not a conspicuous feature of the virgin forest except along streams and lakes, where the cottonwood (*Populus trichocarpa*) and the red alder (*Alnus oregona*) are common and the Oregon ash (*Fraxinus oregana*) is frequently found. The alder also occurs in the forest in places more distant from streams and lakes though it is always most abundant on low ground. It is much larger than the alders of eastern United States and reaches a height of 60 feet or more. The largest of the deciduous trees common in this forest is the broadleaf maple (*Acer macrophyllum*). The vine maple (*Acer circinatum*), a smaller tree with weaker, sometimes sprawling stems is common in wet ravines. Cascara (*Rhamnus Purshiana*) is a small tree abundant in moist places. Willows, especially the Scouler willow (*Salix Scouleriana*), and a flowering dogwood (*Cornus Nuttallii*) frequently occur, and cherry (*Prunus emarginata*) is common in the more open places.

One broad-leaf evergreen tree, the madrona (*Arbutus

Menziesii), is common on bluffs along lakes and seashores and also occurs with other trees in the forest where drainage is good. Evergreen shrubs are abundant. Salal (*Gaultheria shallon*), Oregon grape (*Berberis nervosa*), and a huckleberry (*Vaccinium ovatum*) are among the commonest ones and a large rhododendron (*Rhododendron californicum*) (Fig. 140) is abundant in some places.

A considerable number of deciduous shrubs are also found. The hazel (*Corylus californica*) makes a vigorous growth, often reaching a height of 25 feet or more. The Indian plum (*Osmaronia cerasiformis*) is a smaller shrub, flowering in very early spring. The red huckleberry is mostly deciduous though the young plants and occasionally portions of the older ones are evergreen. Berry-bearing bushes of two genera (*Rubus* and *Ribes*), such as salmon-berry, thimbleberry, blackcap, stink-currant, red-flowered currant, and gooseberries are common.

Ferns are abundant. The common brake (*Pteridium aquilinum*) (Fig. 113) frequently reaches a height of 8 feet in rich forests and the sword fern (*Polystichum munitum*) (Fig. 150), is also large, especially in moist places. The licorice fern (*Polypodium occidentale*) is abundant in the dense growth of mosses and leafy liverworts on trees and rocks. The maidenhair (*Adiantum pedatum*) flourishes on moist banks, and other ferns are common in swampy places.

Herbs are abundant on the forest floor. A large trillium (*Trillium ovatum*) flourishes in eary spring, and a small orchid (*Calypso bulbosa*) is also found. The rattlesnake plantain is found in moist places and its leaves in the form of a rosette persist through the winter. Among the other herbs are youth-on-age (*Tolmiea Menziesii*), the fringed cup (*Tellima grandiflora*), the twisted stalk (*Streptopus*), the false Solomon's seal (*Smilacina*) the wild lily-of-the-valley (*Unifolium*) and wild ginger (*Asarum caudatum*). A striking feature of this herbaceous vegetation is its tendency to remain green all winter.

Lichens and mosses are abundant on trees, rocks and soil, and leafy liverworts (mainly *Porella*) (Fig. 108) form dense growths on trunks and branches of trees in moist ravines.

The decaying trunks of fallen trees frequently support a varied flora. Hemlock seedlings are abundant on them along with mosses, fungi, lichens, and other plants. Mushrooms develop in the decaying matter on the soil when conditions of temperature and moisture are favorable, especially in spring and autumn. Large bracket fungi are conspicuous on many of the conifers.

DESERTS.

Desert communities develop in regions of low rainfall and high evaporation. Two striking examples are the vegetation in the vicinity of Great Salt Lake in Utah and that in the vicinity of Tucson in southern Arizona. In the Utah desert the soil has a high salt content, and it is known as an alkali region. The rainfall is fairly well distributed through the year, though there is a spring maximum and a secondary winter maximum. This community contains practically no succulent plants. The Arizona desert differs from this in certain particulars. Salt is not a limiting factor. The rainfall is more seasonal with a pronounced summer maximum and a winter maximum at least equal to the spring maximum of the Utah desert. Succulent plants are abundant.

The plant community in the vicinity of Great Salt Lake is dominated by low shrubs, which give the aspect to the landscape. Only two or three species of cactus are found, and these not in large numbers. The community consists of little else than xeric shrubs and low annuals. Southwest of the area just described is an area about 100 miles by 50 miles, where the soil contains so much alkali that it supports no seed plants at all. Sage-brush dominates the whole of the Great Basin in non-alkaline soils. The Great Basin includes considerable portions of eastern Washington and Oregon, some portions of Idaho, and most of Utah and Nevada.

The Salt Lake desert described above is at an elevation of approximately 4000 feet. The mean annual temperature at Salt Lake City is 51° F. The average rainfall approximates 16 inches, over one-third of which falls in March, April, and May. The precipitation from October to Feb-

ruary is fairly uniform, with a slight maximum in November. The "dry" season runs from June to September inclusive and has less than one-eighth of the total rainfall. The rainfall at St. George in the southwestern part of the state is approximately 6 inches.

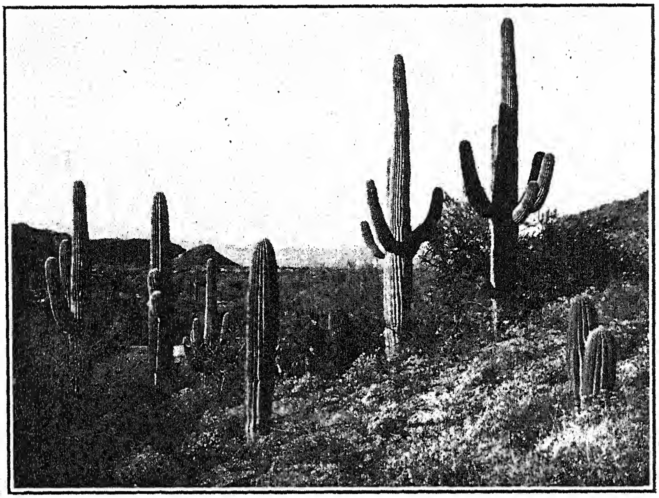

FIG. 151.—Desert vegetation in a canyon in the Santa Catalina Mountains near Tucson, Ariz. The large-branched cacti are the giant cactus (*Carnegia gigantea*). The small cactus near the man is *Echinocactus wislizeni*. The shrubby-looking plants are *Encelia farinosa*. (Photograph by Forrest Shreve.)

Large cacti and scattered shrubs give the aspect to the landscape in the desert of southern Arizona (Fig. 151). The giant cactus sometimes reaches a height of 30 feet, and others are conspicuous by their size. Among the xeric characters of these cacti are their thick, fleshy, practically leafless stems with a large amount of water-storage tissue, and their large root systems spreading close to the surface of the soil. The creosote-bush (*Larrea tridentata*) is a resinous shrub with a strong odor of creosote. Its leaves have such a heavy protective coat of waxy material that they almost appear to have been varnished. The production of

leaves begins in February and they are retained during the greater part of the year. Another abundant shrub is *Encelia farinosa* (Fig. 151) whose yellow blossoms furnish the most striking color of this desert during late winter. Yuccas and agaves are common. Among their xeric characters are thickened leaves and short stems, containing water-storage tissue.

Many low annuals and perennials flourish during favorable combinations of temperature and moisture, the former existing as seeds and the latter as dormant underground organs during unfavorable periods. A few grasses flourish in summer and dry up, furnishing forage for grazing animals.

This community occupies an elevated region where the surface is much broken, and the conditions for plant growth are somewhat different on mesas and slopes and in canyons. Varying combinations of temperature and moisture also make growing conditions quite different at different times of the year. The average rainfall is approximately 12 inches and there are two "rainy" seasons. One of these is in summer, when the average rainfall for July, August, and September totals 5 or 6 inches, and the other in winter when the average for December and January totals 2 or 3 inches. The lowest average is in April, May, and June; the total for these three months being less than 1 inch with less than $\frac{1}{4}$ inch in May.

The mean maximum temperature of the air is 112° F. and the mean minimum 10° F. Freezing temperatures often occur during the winter nights. Remarkably favorable conditions for plant growth occur during the moist summer season, when the day temperature of the soil is up to 100° F. with but slight drop at night. Enormous numbers of seeds which have lain dormant during the unfavorable periods germinate at this time, and the plants grow rapidly often changing the whole aspect of the desert within a few days.

Suggestions for Further Reading.

1. Livingston, B. E., and Shreve, F.: The Distribution of Vegetation in the United States, as Related to Climatic Conditions, Carnegie Publication 284, 1921.

2. The books listed at the end of Chapter XXVI.

CHAPTER XXIX.

PLANT SUCCESSION.

We often notice that plants are entering places where they were not found before and getting established there, and that plants formerly abundant are dying out. Observation thus indicates that plant communities are changing; that they are dynamic, not static. The plant communities that we commonly see have followed other communities and are the result of development. Various plant communities occupy an area in the development of the vegetation from its beginning on bare soil, rock, or water to the time when further developmental changes are impossible on account of the climate. A community that has reached this stage is called a climax community, and the developmental changes leading up to it constitute plant succession.

Plant succession is brought about by definite factors, and these may be grouped as physiographic, climatic, and biotic. It would be impossible within the limits of this book to discuss all of the factors under each of these heads, but a few illustrations will make clear the nature of these factors and the way in which they act on plant communities. Any one of them may produce a bare area (land or water) or may modify the community occupying an area, or two or more factors may act together in bringing about such a result.

PHYSIOGRAPHIC FACTORS.

Among the physiographic factors that are readily observed are erosion and deposit. Streams commonly cut into their banks in some places and deposit the material thus removed in other places. Sand-bars, gravel-bars, and islands are thus built up and on these areas new plant communities start. Lava flows from volcanoes cover areas near by and volcanic

ash carried by wind covers larger areas (Fig. 152). Sand is commonly moved by wind (Fig. 146), and in all of these cases new plant communities sooner or later start on the bare area created. Destruction of forests by rock slides in mountain regions is not uncommon and here the slow development of plant communities begins again.

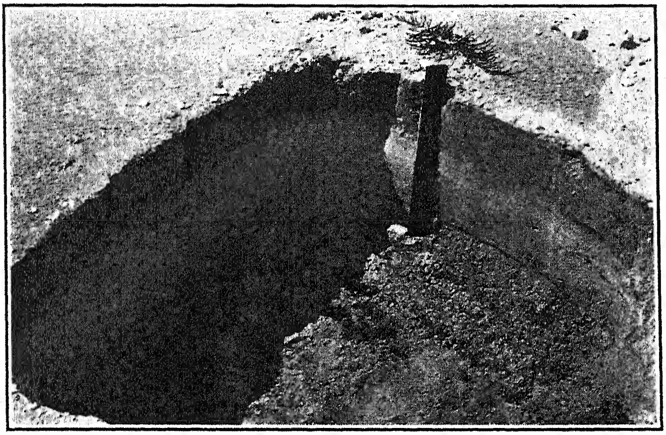

FIG. 152.—Ten inches of volcanic ash near Kodiak, Alaska. A portion of this was removed to expose the old soil with its buried vegetation. A plant of field horsetail is growing in the volcanic ash. The ash came from the eruption of Mt. Katmai in the summer of 1912. (Photograph by S. M. Zeller taken during the summer of 1913.)

CLIMATIC FACTORS.

Climatic factors may destroy or greatly modify plant communities. Among these are snow slides, wind, and fires caused by lightning. Snow slides in mountain regions are common and where they occur year after year they give a definite character to the plant community occupying the area. Wind often almost completely destroys portions of a forest, and forest fires caused by lightning have often been very destructive. Constant watchfulness on the part of forest officials is now maintained in order to locate such fires promptly and extinguish them.

MAN'S ACTIVITIES.

Man's activities are prominent among the biotic factors. He drains lakes and marshes and thus creates bare areas or modifies plant communities. By means of dams he raises

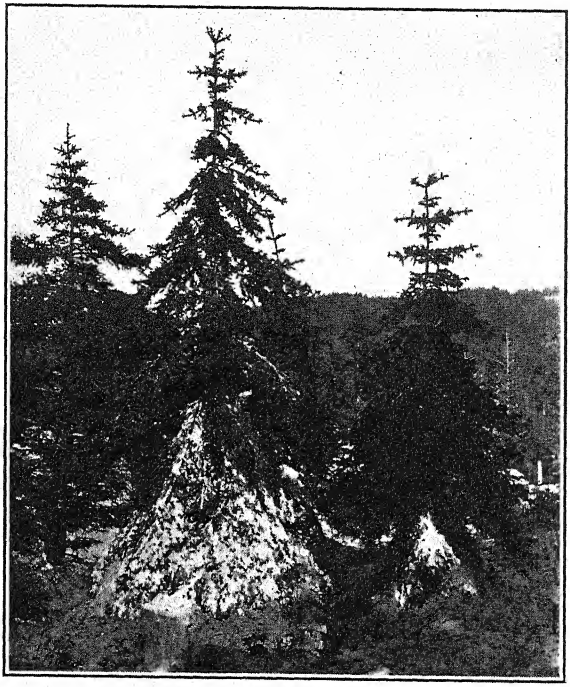

FIG. 153.—Volcanic ash in a spruce forest near Kodiak, Alaska. The ground vegetation is mostly buried and the lower branches of the trees are borne down by the ash. (Photograph by S. M. Zeller, a year after the eruption.) (See Fig. 152.)

the level of streams and lakes and brings about new conditions for the development of plant communities. He cuts the forest, breaks the prairie, strips off the soil in getting out shallow deposits of coal and stone, makes cuts and fills in

building roads, and plants and cares for such vegetation as he desires, and in all of these activities he either destroys or greatly modifies plant communities.

THE ACTIVITIES OF ANIMALS.

Among the activities of animals the work of beavers and burrowing animals may be mentioned. Streams are dammed by beavers and the resulting changes in the level of the streams and often of the lakes from which they come cause new conditions for plants. The aëration of soil by worms and large burrowing animals and the bringing of subsoil to the surface make great changes in the conditions for plant growth.

PLANTS AS BIOTIC FACTORS.

A third group of biotic factors is the activities of the plants themselves. These may be grouped under invasion, competition, and reaction. Invasion involves migration and getting started in the new area. The means of migration are mainly wind, water, and the activities of animals, though plants may get into new places slowly by the growth of their vegetative parts from one small community to an adjacent one. The invasion is of course not successful unless the plant can grow in the new area. Tree seeds blown onto the surface of water or bare rock do not result in successful invasion, while those deposited on soil may do so.

When a plant enters a new community competition for space, water, nutrients and light begins, and the characters of the invader and of the plants already there determine the success or failure of the competition. Many seeds that are capable of germination in a forest do not produce successful plants because of the dense shade, and other factors frequently limit the success of invaders.

If, however, the invasion is successful the invaders themselves show reactions that influence favorably or unfavorably the success of new invaders. Prominent among such reactions are the accumulation of organic matter and the creation of shade. The accumulation of leaves and other plant parts

may produce a substratum in which saprophytes will grow, or, by decay, changes in water-holding capacity and other physical properties of the soil may be brought about and the growth of soil organisms may be increased. As the invaders grow they may shade other plants and thus bring about conditions favorable to some and unfavorable to others.

EXAMPLES OF SUCCESSION.

The establishment of new plant communities is readily observed on bare areas of soil created by grading operations. Among the factors which will determine the constituents of such a community will be the character of the soil, the rainfall and other climatic features of the region, and the seeds that are in the soil or brought to it by wind or other agencies. Weeds frequently form a large part of the first community on such an area, though in many cases an almost pure stand of tree seedlings such as maple, cottonwood or alder occurs where the trees are abundant in the immediate vicinity. Anyone who is interested may easily take a census of such a community.

A quadrat (see p. 341) is often completely denuded for the purpose of studying succession. In other cases only certain plants are removed. Important ecological data are obtained by this experimental use of wholly or partially denuded quadrats.

An interesting study of plant succession may be made where a muddy area has been laid bare by the lowering of the level of a lake. Some plants characteristic of the lake margin persist for a time while other plants, especially those whose seeds are wind-blown, come in. A striking example of this seen in one case was the growth of dandelions along with buckbeans which had survived from the lake community. As the years passed a swamp community became established at the new margin of the lake and a mesic community further back.

A region recently covered with volcanic ash (Fig. 152) furnishes an excellent opportunity for the observation of plant succession. Such an opportunity was furnished by the

eruption of Katmai volcano in Alaska in 1912. Areas which were observed were covered with volcanic ash, varying from 3 feet deep near the volcano to 3 inches at a more distant point. At a place where the ash was about a foot thick the spruce forest (Fig. 153) suffered little injury, but the low herbs were killed. A year later the land plants, other than trees and shrubs, were mostly lupines growing through the layer of ash, and field horse-tail growing on the surface (Fig. 152). During succeeding seasons other species established themselves and thus plant communities were reëstablished.

Floating Mats.—A striking case of plant succession is the formation of floating mats on lakes. Plants forming a dense growth of rhizomes in water are the pioneers in such communities, and two of these occurring widely in the northern portions of the United States, may be given as examples. The buckbean is a perennial herb with fairly stout rhizomes ½ inch or so thick. Its leaves and flower stalks grow from these rhizomes and come above the surface of the water. It is readily recognized by its smooth, three-foliate leaves and its white flowers with fringed petals. The marsh five-finger (*Potentilla palustre*) is known as purple marshlocks in the northwest and bears the botanical name *Comarum palustre* in some of the floras of the region. It produces long slender perennial stems which root at the nodes and these grow forward into the water producing pinnate leaves and purple flowers above its surface These two plants are commonly associated in the formation of mats, though they are often found separately. Sedges (*Carex*) are early pioneers on this mat, and the three soon form a substratum on which a more varied community of hydrophytes flourishes. As the mat becomes old and firm a mesic community follows. Land whose surface is an old mat of this sort is frequently utilized as pastures or meadows, and in some cases even for cultivated crops. Cases are not uncommon where all of the stages from open water to a flourishing garden may be seen within half a mile. Many species enter into the formation of floating mats and the community involved is often very complex. Only the general character of mat formation is here indi-

cated. Line transects and belt transects (see p. 341) furnish a convenient means of making a systematic study of such successions.

Sphagnum Bogs.—Plant succession is very obvious in *Sphagnum* bogs. These bogs are common in northern United States, southern Canada, and northern Europe. A stage in their development which is commonly seen (Fig. 155) is that in which a substratum, consisting of *Sphagnum* moss, (Fig. 112) supports a dense growth of low shrubs, such as Labrador tea (*Ledum*) and swamp laurel (*Kalmia*), among which grow the small vines of the wild cranberry (*Vaccinium Oxycoccus*). Insectivorous plants, such as sundew (*Drosera*), also flourish. The development of these bogs in two ways—on lakes and on swamps—is commonly seen.

On lakes (Fig. 155) they form floating mats. In one type of development the *Sphagnum* follows on a mat formed by buckbean, marsh five-finger, and small sedges, and the other members of the bog community follow close behind. In another type of development the bog community itself moves forward onto the open water without the aid of other plants. The woody stems of the bog shrubs grow out into the water and curve upward at the tip so that their leaves are in air. *Sphagnum*, sedges and sundew follow close behind, and the typical bog community is thus seen only a few feet from the open water.

Sphagnum bogs also develop on swamps. *Sphagnum* is frequently the pioneer in such an advance, in some places forming at first only a sparse growth among the swamp plants, and in other places growing more vigorously so that there is a difference of a foot or more between the level of the surface of the moss and that of the substratum of the swamp into which it is advancing. *Sphagnum* often advances on swamp thickets of shrubs as well as on swamp communities such as those described on p. 371. Some *Sphagnum* is often found in marshes without other bog plants, but where a bog joins a marsh the general tendency is for the bog community to advance on the swamp.

Plants of the earlier plant communities are frequently found growing in the bogs of the Puget Sound region. In

those that have advanced on lakes the water-lily (*Nymphæa*) is commonly found growing in the *Sphagnum* at a distance of 100 feet or more from the open water, though it is generally killed out as the bog becomes more mature. The rhizome is under the *Sphagnum* and the leaves and flower stalks grow up through an opening. This opening is finally closed by the growth of mosses (mainly other than *Sphagnum*) and the

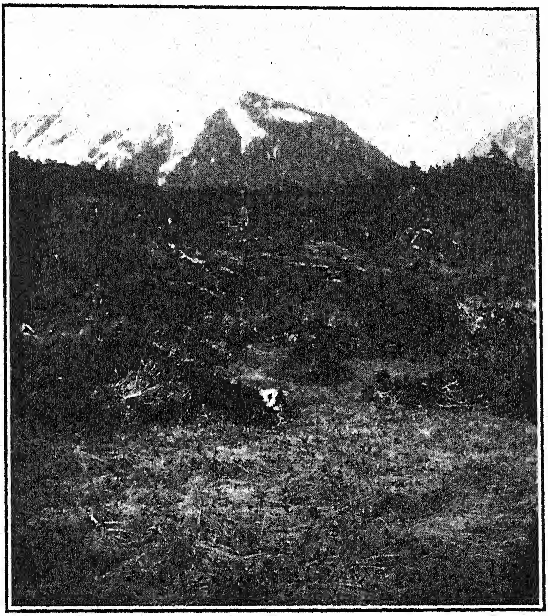

FIG. 154.—A *Sphagnum* bog near Dixon harbor, Alaska. The prostrate trees are *Pinus contorta*.

water-lily dies. Skunk cabbage (*Lysichiton*) (Fig. 133) is common in the early stages of bogs that have developed on swamps. It is rooted in the muck of the swamp which the bog has overrun and its huge leaves and flower stalks grow up through an opening in the *Sphagnum*. In later stages of the bog succession it is killed out in much the same way as the water-lily.

A series of forest stages (see Fig. 155) follows the mature stage of these bogs. This forest in the bogs of northwestern United States is most commonly composed of conifers, such as hemlock, spruce, white pine or lodge pole pine. Stages from seedlings up to trees 30 to 40 feet tall are commonly seen. Birch often forms the forest stage in bogs in regions where it is common in the neighboring forest.

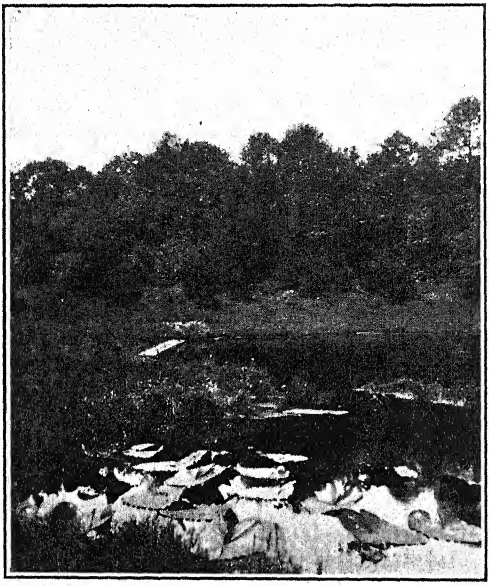

FIG. 155.—A Puget Sound *Sphagnum* bog encroaching on a small lake. Water lilies (*Nymphæa*) in the lake. Coniferous trees growing in *Sphagnum*. Forest of coniferous trees with some alders in background (on clay soil).

Much attention has been given to the fact that the ordinary plants of the region, except forest trees, are not very successful invaders of these bogs. A study of the physiological conditions has brought out the following facts: (1) The temperature of the substratum is lower than that of the ordinary soil in the immediate vicinity. (2) The water table is so high during much of the season that air is excluded from the

substratum. (3) The gases dissolved in the soil water show a high proportion of carbon dioxide and a low proportion of oxygen. (4) The soil water has rather high acidity (pH 3.5 to 5.5). To what extent these or other factors operate, which one of them may be the limiting factor, or whether some other factor may be the limiting one has not been fully determined.

Much attention has also been given to the fact that such shrubs as Labrador tea, swamp laurel, and some others common in bogs show structures that are usually considered xeric. Labrador tea has inrolled leaves with stomates on the lower surface only, and this surface is covered with a dense woolly growth of hairs. In addition to this the stomates are sunken beneath the surface of the epidermis. The substratum is wet, and xeric characters in the leaves of plants growing in it do not seem natural. In several cases either the bog shrubs or species and varieties closely related to them are also found in cold northern regions and on mountains in the northern portion of the temperate zone. A view commonly held is that xeric structure in these plants was correlated with the physiologically dry conditions of a cold region, and that on the retreat of the glaciers and the coming of warmer conditions they found their most congenial habitat in the bogs.

By sampling the peat under these bogs much has been learned about the plant successions of long ago (Fig. 156). The organic matter in many of them is from 10 to 20 feet deep and in one case it was found to be 43 feet. In many of these bogs the peat formed by *Sphagnum* is only 2 or 3 feet deep, rarely more than 4. Sedge peat is commonly found underneath this and layers of sedge peat may alternate with layers of woody peat or of material consisting mainly of mud. The deeper layers of many of these peat deposits are sedimentary and consist of very finely divided organic matter that has evidently been deposited from quiet water. All of the layers of peat in these bogs (Fig. 156) tell their story of the succession of lake, forest, or swamp communities that have occupied the area or of the inflow of muddy water due to physiographic or climatic factors.

Succession in a Forest.—In the mature Douglas fir forests of the Puget Sound region evidence of the succession to come is clearly seen. Though the Douglas fir is the dominant tree,

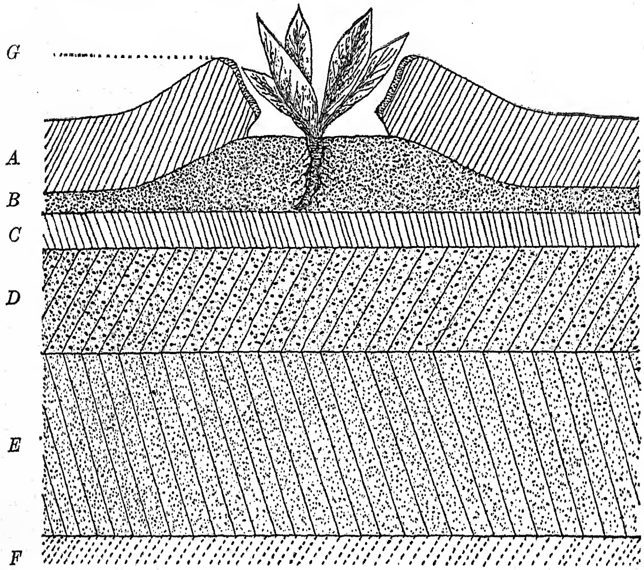

FIG. 156.—Section of a Puget Sound *Sphagnum* bog.

A. Surface layer of *Sphagnum teres* peat (2 feet thick) containing root systems of present flora, notably Labrador tea (*Ledum*), pale laurel (*Kalmia*) and cranberry (*Vaccinium*) and also many old leaves of these plants.

B. Layer of brownish-black mud (6 inches thick) in which the skunk cabbage plant is growing.

C. Layer of *Sphagnum palustre* peat (8 inches thick) containing an abundance of leaves of cranberry with some leaves of hemlock, pale laurel, and grasses, and twigs of cedar (*Thuja plicata*).

D. Layer of forest peat (3 feet thick), consisting of wood detritus and bark mixed with leaves, twigs, and cones of cedar; leaves and twigs of hemlock; leaves of Labrador tea, pale laurel, salal (*Gaultheria*), and grasses; seed wings of western white pine; and whole plants of a moss (*Camptothecium sylvaticum*). One large stump *in situ* was found.

E. Layer of sedge (*Carex*) peat (almost 5 feet thick), highly moldered below, with leaves of pale laurel and Labrador tea, an abundance of a true moss (*Hypnum gigantium*), and sparse *Sphagnum*.

F. Clay.

G. Thin layer of peat around the opening, formed from mosses other than *Sphagnum*. (From Turesson, Am. Jour. Bot., 189, vol. 4.)

often constituting 90 per cent of the forest, its seedlings are rarely seen on the forest floor. Hemlock seedlings are abundant in the humus of the soil and on fallen logs. This abundance of hemlock seedlings and scarcity of fir seedlings is apparently due to difference in their relation to organic matter and light. Hemlock seeds germinate well in organic matter and the seedlings grow well in it. They are also tolerant of shade. Douglas fir seedlings, on the other hand, germinate best in mineral soil such as clay, and their seedlings do best in it. They are also very intolerant of shade. The situation described indicates that a succession of hemlock would eventually follow the fir forest as it decays, and would dominate the climax community if Nature were left to its course.

General Tendencies of Succession.—In general the tendency of succession is toward the most mesic association that the climate will allow. This may be illustrated by considering the succession on bare rock and the succession on open water, both finally producing a forest climax. On bare rock crustose lichens first appear, and these are followed by foliose lichens. The next stage is commonly mosses, and this is followed by the herb stage. The shrub stage follows this and eventually gives place to a forest succession. All of the stages from bare rock to a deciduous forest have been carefully worked out, and the plants forming each succession are well known.

On open water the first stage may be submerged plants followed by a succession of water-lilies and other plants that send some of their parts above the surface of the water. This may be followed by a stage in which sedges and rushes are dominant. Trees growing in wet places (willows, cottonwoods, and alders) follow, and they are commonly followed by a community dominated by ash and other trees that flourish in moist soil. Other forest successions follow, leading to a climax forest dominated by deciduous trees.

Suggestions for Further Reading.

1. The books listed at the end of Chapter XXVI.

2. Davidson, J. Conifers, Junipers and Yew: Gymnosperms of British Columbia.

PART V.

SOME GENERAL PHASES OF BOTANY.

CHAPTER XXX.

BOTANY IN RELATION TO OTHER FIELDS OF KNOWLEDGE.

BOTANY overlaps many other fields of knowledge. In some cases it has subject matter in common with these fields, in some cases it has concepts in common, and in other cases it has methods in common. In many cases it profits by the advance of knowledge in other fields and by the criticism of workers in these fields. Botany has now become such a complex science that it is necessary for those who are contributing to its advance to have a general understanding of at least some of the fields on which it borders or overlaps, and even those who are seeking only a general understanding of the part that plants play in the environment of man will profit by some acquaintance with its relation to other fields of human understanding. In the following discussion there is no attempt to cover all of these points of contact. The intention is merely to cite some illustrations, and many others will, no doubt, occur to the reader.

BOTANY AND ZOÖLOGY.

Botany has very definite relations to other natural sciences, such as zoölogy, chemistry, physics, geology, and mathematics. Among the points that botany and zoölogy have in common are: (1) that both deal with living things composed

of cells; (2) that the boundary line between plants and animals is not a definite one; (3) that they both deal with many of the same concepts; (4) that plants and animals have several functions in common; (5) that many of the methods of study and investigation in the two fields are similar; (6) that the divisions of the two subjects are strikingly alike; and (7) that plants and animals together form the subject matter of some rather specialized sciences.

The fact that these two sciences both deal with living things leads the botanist and the zoölogist to be mutually helpful in bringing out the nature of living matter and the differences between it and non-living matter. One of the great advances in biology was the generalization brought out about a hundred years ago, that all plants and all animals are alike in that they are composed of cells. Both sciences have in common the as yet unsolved problem of the origin of life.

The boundary line between plants and animals is so indefinite that the same organisms are frequently studied in both botany and zoölogy. As a matter of fact, there are really no definite characters that can be taken as absolute distinctions between the two kingdoms. The important thing is to understand these border-line organisms rather than to attempt to assign them definitely to either kingdom.

One of the most interesting of these groups of organisms is the slime molds (Myxomycetes) (see p. 172), in which every individual exists during its life history in two phases: one strikingly animal-like and the other strikingly plant-like. The first phase is a mass of slimy protoplasm (Fig. 70) growing on decaying wood and other objects in moist, rather dark places, and showing no plant characters whatever; the second (Fig. 71) is a fruiting phase in which the erect stalks are produced with cases of spores at the top, these spores reproducing the slimy stage. This second stage shows very definite plant characters.

Another group is the flagellates (see p. 174). These are one-celled organisms (Fig. 72), living in water and moving about by means of whip-like processes, called flagella. Many, though not all, of these organisms are green and thus

suggest plants. This does not, however, furnish a definite basis for deciding that they are plants, for many rather simple organisms with unmistakable animal characters are green. The locomotion of the flagellates by means of flagella is often thought of as an animal character, but this means of locomotion is found in some plants, such as the bacteria. The flagellates reproduce by division of the mature organism into two new individuals, and this method of reproduction is common in one-celled organisms, both plant and animal. A red spot sensitive to light is found in each individual in many species. This is called the eye-spot, and is usually thought of as suggesting that the organisms are animals. This spot does not, of course, form any image of objects, hence has little in common with animal eyes, and fairly definite regions responding to the stimulus of light are common in plants. There are several other groups of organisms on the border-line between plants and animals, but these two groups are sufficient to illustrate the subject.

Among the concepts that botany and zoölogy have in common are organism, organ, function, and cell. An understanding of these concepts is best obtained by considering examples from both kingdoms. Some understanding of what an organism is is necessary in order to appreciate man's place in Nature. Both plants and animals are organisms, though the plant organism is in general somewhat simpler than the animal organism. Both plants and animals that show differentiation of parts have organs, and the cells composing these organs are more or less differentiated.

Among the functions that plants and animals have in common are digestion and respiration. Higher animals have specialized organs with which they perform these functions, while even the highest plants lack special organs for them, and in most cases perform them by means of cells, which also serve other functions. In one-celled animals and one-celled plants the performance of these functions is strikingly similar.

Among the methods of study common to botany and zoölogy are the use of the microscope and of the technique of preparing material for microscopic examination. Both sciences have advanced with the perfection of the compound

microscope and of microscopic technique. The use of observation and experiment (see p. 404) is also similar in the two sciences in many cases.

Several of the fields of study within each of these two sciences have received the same names and are in general quite similar. Taxony, morphology, physiology, and ecology are divisions of both botany and zoölogy, and the study of any one of these in the plant kingdom has much in common with its study in the animal kingdom.

Both plants and animals cause diseases of many plants as well as of animals, including man. The smaller ones of these causative organisms are grouped together as micro-organisms, and form the basis of the study of both plant and animal pathology. There are also many animals and some plants that are large enough to be seen with the unaided eye that cause pathological conditions of both plants and animals. The study of genetics (see p. 318), which consists in finding out the facts about the inheritance of characteristics, forming concepts on the basis of these and attempting to formulate laws in regard to the facts and concepts is now commonly carried on with both plant and animal material.

BOTANY AND CHEMISTRY.

The relation between botany and chemistry is a very close one. Among the important points in this relationship are: (1) that many plant processes involve chemical reactions in the plants; (2) that qualitative and quantitative analysis of plant organs and tissues constitute an important means of increasing our knowledge of plant functions (see p. 143); (3) that physical chemistry, especially the chemistry of colloids, contributes much to our understanding of the nature of the protoplasm of plant cells; (4) that historically, chemical discoveries have in many cases led to important advances in our knowledge of the life processes of plants; (5) that in some instances botanists have through their study of plant functions contributed important data to chemistry.

Photosynthesis (see p. 142) is an excellent example of the life processes of plants that involve chemical reactions.

This process consists in the union of carbon dioxide and water in the presence of light and chlorophyll to form carbohydrate foods, such as starches and sugars. The study of this process involves not only a knowledge of the conditions in the living green cells of the plant, but also a knowledge of the chemical reactions that constitute the various steps in this process. These steps are imperfectly understood at present, and botany and chemistry must go hand in hand in further progress. A general knowledge of photosynthesis may be gained without any very great amount of chemical knowledge, but a thorough understanding of our present knowledge of the process necessitates a knowledge of both inorganic and organic chemistry. In order to understand the manufacture by the plant of sugars from carbon dioxide and water it is necessary to know just what sugars are present in green leaves, and it is highly desirable to know exactly what quantities of the various sugars are present. Courses in tissue analysis have become an important part of the training of plant physiologists.

Respiration, which consists in the breaking down of organic foods, such as sugars, with the release of energy, is another plant process involving chemical reactions. Digestion likewise involves chemical processes, since it consists in so changing the molecular constitution of foods that they are transformed from an insoluble state to a soluble state, and from a state in which they cannot diffuse from cell to cell to one in which they can diffuse. Still another illustration is the entrance of water into the living cells of the plant, a process which involves osmosis, a physico-chemical process.

The number of books that have appeared in recent years on physical chemistry in relation to biology indicates the importance of this field. Since we have come to think of protoplasm in terms of the concepts of colloid chemistry, and of the cell in terms of a physical system, we have been able to unify much of our knowledge of protoplasm and of cell activity which formerly consisted of isolated facts.

The impetus given to the study of photosynthesis by the work of the German chemist, Willstaetter, since 1900, on the chemistry of chlorophyll and its accompanying yellow

pigments is well known. The contributions of Pfeffer and of De Vries to our knowledge of osmosis are examples of the contributions of botanists to chemistry.

Chemistry is not absolutely necessary for the study of all phases of botany. Taxonomy and morphology may be studied without much reference to it. Chemistry, is, however, highly desirable as a background for general botany and is necessary for physiology and ecology, and for at least some phases of pathology and genetics.

BOTANY AND PHYSICS.

Physics has many important relations to botany. Many of the functions carried on by plants involve processes whose understanding is based on physics. The process of the entrance of water from the soil into the cell walls of roots is called imbibition and is a physical process. The movement of water in the soil toward the roots of the plant involves capillarity and surface forces, and these are also physical. Physical principles are involved in the rise of water in tall plants, such as trees.

The study of photosynthesis involves the measurement of the intensity and wave length of light, and these are physical measurements. The knowledge of the absorption spectrum of chlorophyll (Fig. 68) is also fundamental in the study of photosynthesis, and this is physical knowledge. A knowledge of the cooling effect of the evaporation of liquids is important in the understanding of transpiration in plants (see p. 140). This is also physical. Physics has also contributed to the perfection of the compound microscope and its accessories, and this in turn has contributed a good deal to the progress of botany.

Chemistry and physics together have contributed much to advances in plant physiology and ecology.

BOTANY AND GEOLOGY.

The field of geology overlaps that of botany in several places, among which are: (1) paleobotany; (2) the origin and nature of soils; (3) physiographic changes in the earth's

surface. Fossil plants are found in geologic strata, and the investigation of these involves a knowledge of both geology and botany. Some of these fossil species do not now exist as living species, and a study of the fossil remains of these has bridged over some gaps in our knowledge of the morphology and evolution of plants, *e. g.*, the gap between the ferns and the seed plants (see p. 290). A knowledge of plant fossils along with the knowledge of animal fossils is also the basis of much advance in geological knowledge.

Plants grow in soils, and these soils originate largely from disintegration of the rocks composing the surface of the earth. Some knowledge of geology aids much in an understanding of soils. Plants also influence the formation of soils by the breaking and solution of rocks.

Physiographic changes in the earth's surface, both those observable in progress at the present time and those that took place long ago, are correlated with changes in the plant communities occupying various areas (see p. 349). A knowledge of these changes helps much in the understanding of changes that occur in the plant societies occupying any given area, and an understanding of plant societies and their relation to environmental factors is also beginning to contribute to the advance of historical geology. Paleoecology is now recognized as a subscience involving both botany and geology and is already engaging the attention of trained workers. The progress of certain phases of botany as well as of geology will depend in the future on persons trained in both fields, and the interrelation of the two subjects is thus very important.

BOTANY AND MATHEMATICS.

Recent years have seen much advance in the appreciation of the relation of mathematics to botany. Statistical methods developed by mathematicians are necessary to the interpretation of many of our botanical data. Mutual criticism of these methods and of their application to botanical problems by both botanists and mathematicians has contributed to the perfection of the methods and their

applications. The careful arrangement and tabulation of our data are good and constitute a great advance over merely stating them in sentences, but we express them still more briefly and effectively in curves. Where our knowledge is sufficiently exact, the use of mathematical formulas is becoming common.

We do not mean that extended courses in all of these sciences are necessary before taking a general course in botany, for that would for most persons preclude ever taking a course in botany. We do mean that the work of the specialists in these sciences has contributed much to an understanding of botany, and that some appreciation of the general situation is important for an understanding of botany and of its contributions to the understanding and enjoyment of our environment.

BOTANY AND THE SOCIAL SCIENCES.

Among the social sciences whose relation to botany is obvious are sociology, economics, and history. Some of the points that botany and sociology have in common are: (1) that both plants and human beings are influenced by their environment and that the environment is in both cases composed of many factors; (2) that both plants and human beings form groups or communities related to their environment; and (3) that many of the principles of the formation of these communities and of their relation to the environment are common to plant communities and human communities. The recent rise of the science of human ecology is the result of the recognition of these points.

In the relation of economics to botany two points are evident: (1) Plants furnish many materials that enter into commerce. This phase of economics is of interest to botanists, and at least some general knowledge of the principles of plant production is desirable for the economist. (2) Advance in botanical knowledge often changes economic situations, and conversely, changes in economic conditions often stimulate advances in botanical knowledge. Some acquaintance with the overlapping field of these two sciences

will often enable both the botanist and the economist to look forward with clearer vision.

The historical viewpoint is important in understanding the present status of botany, and a knowledge of history is essential to this viewpoint.

BOTANY AND APPLIED SCIENCES.

Among the applied sciences in which botany plays a part are medicine, pharmacy, bacteriology, agriculture, horticulture, forestry, and fisheries. As any phase of botany becomes economically important and develops highly specialized methods, it tends naturally to split off and become a separate science, the botanical phases of which are somewhat overshadowed by the economic phases and the specialized methods. This has many advantages, but it leaves a border-line between botany and these other fields which should be the subject of careful study lest, to use an agricultural figure, we cultivate the separate fields carefully but allow the fence rows between them to grow up with noxious weeds.

Medicine and pharmacy may be considered together. The use of plants and their products in the treatment of diseases and injuries has engaged a portion of the attention of the human race for many centuries. At the present time about 300 official drugs in the United States are of plant origin and many unofficial drugs of plant origin are in common use. In recent years we have come to depend more and more on the cultivation of drug plants and less on the mere gathering of wild plants and a knowledge of the botany of drug plants has thus become very important.

Bacteriology is concerned with microörganisms (see p. 210), a very large number of which are plants. Some of the important phases of this science are the causation of the diseases of man and other animals, the relation of soil organisms to the growth of crops, and the part played by microorganisms in industrial processes. There is thus a very important border-line between botany as a pure science and bacteriology as an applied science, though it is perhaps better

to emphasize the relation to biology in general than to botany in particular. This overlapping field is engaging the attention of both bacteriologists and biologists.

Agriculture may be considered as an art to which many sciences contribute. Since it has much to do with the growth and qualities of plants, a knowledge of plant physiology, ecology, and genetics is very important in it, and taxonomy and morphology also make their contributions. Much the same statement applies to horticulture, with such specialized phases of botany as vegetative propagation by budding and grafting and by the use of cuttings assuming great importance. Botany also contributes much to the safe storage of fruits and vegetables and to artificial means of hastening their ripening.

Forestry has in recent years become a very important and highly specialized field of applied science, some of the phases of which, such as logging engineering, have little to do with botany, while others, such as silviculture, are closely connected with plant physiology, ecology, pathology, and other phases of botany.

In the field of fisheries a knowledge of the biological relationships between plants and animals in both fresh and salt water is very important. Diatoms and other microscopic plants constitute an important direct or indirect source of food for fish and other aquatic animals that are used for human food. Some algæ and even some higher plants are eaten by some fish. Submerged vegetation furnishes a place of resort for aquatic animals, and in many cases the eggs of these animals are deposited on plants. Plants under water in sunlight are also an important source of oxygen for the aquatic animals.

BOTANY AND PHILOSOPHY, LITERATURE, AND ART.

Some other fields of knowledge to which botany has more or less definite relations are philosophy, literature, and art. The philosophical attitude is important in all scientific work in so far as it leads to critical examination of data and of the

methods of reasoning used in dealing with them, and to the formulation of hypotheses which may be tested out by observations and experiment. In literature biological concepts and generalizations about both plants and animals are commonly used, and it is important that these be used understandingly and not as mere words.

The relation between biology and art is a little more difficult to state in an exact way, but its existence is commonly recognized. Some knowledge of the form and structure of both plants and animals is desirable in sculpture and painting. Scientific and artistic systems embody the same fundamental principles of the relation of living things to their surroundings. The pleasure of the biologist in establishing the interrelationships of the facts and concepts of his science is closely akin to the pleasure of the artist in the successful creation of a picture, a statue or a symphony. Certain phases of biology and certain phases of art employ the same general principles, and a person who enjoys art will also enjoy certain phases of biology if they are presented in such a way as to bring out relationships.

CHAPTER XXXI.

THE GROWTH OF BOTANY AS A SCIENCE.

THE METHOD USED.

BOTANY, like other sciences, has been brought to its present state by the use of what we call scientific method. This consists essentially in acquiring facts and drawing conclusions from them. We have acquired our facts by observation and experiment. Historically, observation came first, and for a long time there was little use of experiment. We use this same sequence in acquiring facts about plants at present; we first observe what sort of plant or organ we are dealing with and also any other facts that bear on the case, then if these facts are not sufficient basis for an inference or conclusion, we plan experiments to give us more facts. Often observation gives us sufficient facts, and experiment is unnecessary, though there is a growing tendency toward experimentation wherever possible.

Scientific method came into use about 1700. The thinking of the Greeks was strict and logical, but they did not develop to any great extent the habit of patient and minute observation. During the early part of the Middle Ages man's chief concern with Nature was the business of wresting a living from it. But with the accumulation of wealth, the rise of the universities, the growth of leisure, and the invention of printing there gradually developed the habit of bold thinking based on well-established facts, and scientific method was the result.

The Acquisition of Facts About Plants.—By observation we find out about the parts of plants and the varieties of form and structure shown by these parts. We see that plants are composed of organs, and learn about the form and external characters of these organs. By tearing them to pieces and

by cutting sections of them we find that they are made up of various tissues. By the use of the microscope we learn that these tissues are composed of cells, and observe how these cells are associated in the tissues. We observe the visible parts of the cells, and by methods recently devised we may even dissect the cells and observe more about the nature of their parts. These facts all come by observation, whether we use the unaided eye or whether we use a hand lens or a compound microscope as an aid.

We also observe many facts about the behavior of plants and their relation to their environment. We see that many trees and shrubs lose their leaves in autumn, while others do not; that plants wilt and finally die when not supplied with water; that many plants turn their tips toward light; that some plants flourish better in full sunlight, while others do better in shade; and that plants under a box or a board on the lawn do not become green. Many of these relations to environment may be made the subject of experiment, but they are often observed where no special conditions have been intentionally created.

By observation we readily acquire a considerable stock of facts about the gross and microscopic anatomy of plants and about their behavior and relation to their environment.

Experiment is a very interesting means of acquiring facts about plants. An experiment may be defined as a question put to Nature, and we put the question by creating a certain condition and observing what response we get as a result of this special condition. We grow seedlings in the dark and find that they do not become green, or we put a green plant in darkness and find that it eventually loses its green color, and we find by tests that it does not form starch even during the time that it retains its green color. If we fill a bottle with dry beans and place it in water we find that in the course of a few hours the beans take up water and swell so that they break the bottle. We may readily experiment on plant cells under the microscope by mounting one moss leaf in water and another from the same plant in a salt solution. It is found that in the first leaf the soft part of each cell completely fills the space within the wall and the chloroplasts

are distributed through the whole space, while in the second, the soft part of the cell draws away from the wall and the chloroplasts are thus crowded together.

It is often desirable to run a control for an experiment in order to be sure that the result that we perceive is due to the special condition that we create. A control for the experiment in which we grow seedlings in the dark would be arranged by growing seedlings from other seeds of the same lot under conditions similar in every way except that they are in light instead of darkness. If we find that the seedlings are green when grown in light and not green when grown in the dark we have a definite fact about the relation between light and green color in seedlings from this particular lot of seeds. In the experiment on the moss leaves the one mounted in water is a control for the one in salt solution, and we have definite information about the difference between the behavior of the cells of leaves from this particular moss in water and in salt solution. We might acquire this information about one leaf by mounting it in water, then placing a drop of salt solution at the edge of the cover-glass and observing the effect on the cells as the salt diffuses through the water. Controls for the other experiments mentioned may be readily devised. A control for an experiment is arranged by duplicating all of the conditions of the experiment except one. Some experiments may be of such a nature that the facts are obvious without a control, but where there is room for doubt the control should be run. Control observations are often just as necessary as control experiments.

The first step, then, that we make in getting acquainted with plants is the acquisition of facts, and these facts are acquired by observation and experiment. Observation is, of course, used in getting the results of experiments, and though observation may be used alone, the two methods of getting facts frequently go hand in hand. Observation may be sufficient to give us the facts in some cases, while in others it may give us facts that lead us to perform experiments in order to understand the situation more fully.

The Making of Generalizations.—Having acquired a stock of facts about plants by observation and experiment, we

begin to attempt inferences or conclusions from them, and thus start on the process of making the broad generalizations that mark the advanced stages of any science. Before attempting generalizations about any phase of our knowledge of plants it is advantageous to sift out the available facts, rejecting those that do not apply to the case in hand, then to arrange the sifted facts systematically so that we may most readily see their meaning. Tabulation is always a useful method of arranging facts for this purpose, and in many cases, such as studies of the functions of plants, the plotting of curves is desirable. When we thus have many data bearing on some one point we make an inference or formulate a theory. We then examine the facts again to see if they all support the inference or fit into the theory. If they do not, we repeat the observations and experiments, either verifying the facts or showing that they are not facts. We may thus need to modify the inference or theory until we get one that fits all of the facts, and we hold ourselves ready to modify the theory at any time if new facts inconsistent with the theory are verified. The progress of our knowledge of the nature of the vessels that conduct liquids through the stems and other parts of plants will illustrate this. It was once thought that these vessels were not of cellular origin, and that the tubular parts of plants were thus to be distinguished from cellular parts. Further study, however, showed regularly occurring lines around these tubes, and these were inferred to indicate the fusion of cells in the formation of the tubes. Studies in the early stages of the formation of vessels confirmed this view, and these facts eventually fitted into the generalization that all parts of the plant are formed by cells.

The method just described consists essentially in making generalizations on the basis of a large number of facts, and is called inductive reasoning. This is the method of reasoning to which the science of botany largely owes its present state.

When we have arrived at generalizations by inductive reasoning, we may draw conclusions as to specific cases by applying these generalizations. Willow trees, at least in the

temperate zones, lose their leaves at the approach of winter, and when we have identified a tree as a willow we may predict, even when it is in full foliage in summer, that it will lose its leaves before winter. This is deductive reasoning and may be used in predicting the future. By such reasoning we predict that if the season is very cold or very dry the corn crop will be poor or that if there is frost within a certain time in any given locality the fruit crop will be destroyed.

A third form of reasoning sometimes used in botany consists in drawing conclusions by observing certain facts where we do not know the cause, and reasoning that these facts are due to the same conditions that we have elsewhere seen producing similar results. We observe that the leaves of a plant are rolled up, and we infer the presence of an insect, called a leaf-roller, even before we examine the leaves, because we have previously seen this effect produced by leaf-rollers. Such reasoning is called analogous reasoning, and great care is required to avoid error in its use. Fortunately in the case mentioned we may examine the leaves and find out whether leaf-rollers are present, and if time permits we may observe stages in the rolling up of leaves when the insects attack healthy ones. Errors may be made, however, where we cannot find out by observation or experiment whether the case under consideration is similar in all essential particulars to the case where the cause is known. If the two cases can be shown to be alike, analogous reasoning will lead to a correct conclusion, and the method is useful in such a case.

The botanist, like other scientists, must use his imagination, but must keep it under control. Proper use of the imagination suggests lines of observation and experiment that will show whether the position taken is true or false, and anything imagined about plants immediately suggests a program for work which engages the attention of many investigators.

Scientific method is clearly distinguished from other methods used in arriving at what is believed, or at least asserted, to be truth, such as dogmatism. Examples of this in reference to plants are common. The dogma of the constancy of species was for some time a detriment to the

progress of botany, but it finally lost its influence as scientific method was applied to the case.

The habit of using scientific method is valuable in everyday life, since it leads us to seek all available facts before attempting to draw conclusions, and to examine carefully the methods of reasoning used in drawing conclusions. Though this influence acts slowly, it is certainly at work. Its advance would be more rapid if trained scientists would learn to use scientific method when they have occasion to deal with fields outside of their own.

SOME STEPS IN THE PROGRESS.

The Origin of Botany.—Man's earliest interest in plants was undoubtedly concerned with their use as food, and his interest in them as medicine is very ancient. No exact date can be set for the origin of botany. Our knowledge about plants has, of course, been a growth, but this growth has not been steady, and there are three points in it which deserve discussion as possible approximations of the founding of the science of botany. These are: (1) the third century B.C., because of the inquiries and writings of Theophrastus of Eresus; (2) the sixteenth century A.D., because of the work of the herbalists, Cordus, Bock, and others; and (3) the middle of the eighteenth century, because of the work of Linnæus. According to the first idea, botany is of Greek origin, and is approximately twenty-two centuries old; according to the second, it is of German origin, and is a little less than four centuries old; while according to the third, it is of Swedish origin, and is less than two centuries old.

There seems to be good reason for thinking of Theophrastus as the father of the science of botany. He was a pupil of Aristotle, and, although he had a good deal of the philosophical viewpoint of his master, he knew many facts about the organs of plants and their functions and also about the kinds of places in which various plants grow. He recognized root, stem, branch, twig, and leaf, and gave physiological definitions to the first two. He did not define leaf, but

described fully several kinds of leaves. Aristotle had classified plants as trees, shrubs, and herbs, and Theophrastus grouped them as woody and herbaceous, and subdivided the latter group into annual, biennial, and perennial. He recognized sepals and petals as modified leaves and the flower as a modified branch. Though he had no microscope of any sort, he recognized the essential differences in stem, leaf, and seed between the two groups, Monocotyledons and Dicotyledons, and had some idea of the formation of annual rings in wood. He recognized that plants form communities, and gave lists of the plants forming the communities of woodlands, marshes, lakes, and rivers. He taught botany in the garden which he had inherited from his master, and by his published works and his teaching he laid the foundations of botany.

Though the Greek physician, Dioscorides, and the Roman physician, Galen, wrote about plants from the medical standpoint in the first and second centuries A.D., they contributed little of a botanical nature, and after them the history of botany is practically a blank for fourteen centuries. Then the herbalists of the sixteenth century revived interest in plants, and there has been considerable tendency to call them the fathers of botany. They listed and described plants and made some attempts at discovering their natural relationships, though they still emphasized medicinal virtues. Probably the most important of these was Cordus (1515–1554). He studied at the University of Wittenberg and gave lectures there on Dioscorides. He went direct to Nature for his information, and was "the first to teach men to cease from a dependence on the poor descriptions of the ancients and to describe plants anew from Nature." Bock was another herbalist who described plants at first hand, and thus helped in reëstablishing botany as a science. Two other herbalists of the time, Brunfels and Fuchs, did much to revive interest in plants, but, though they illustrated their works with excellent wood-cuts, they seem to have depended largely on the descriptions given by ancient authors rather than on their own observations. Nearly a hundred herbals in Latin, German, Italian, French and English were published between 1470 and 1670, and some were published later.

The Swedish botanist, Linnæus (1707–1758), is often spoken of as the father of modern botany. He studied medicine at the University of Lund, where he also gave botanical lectures and managed the botanical gardens. He traveled in several countries, was a physician in Stockholm for a few years, and then became professor of botany in Upsala University, where he remained until his death. Though he wrote some works on the general nature of plants, he contributed few important discoveries in this field, and his main work was in classification and description. He emphasized the idea previously suggested by others, that there is a natural system of classifying plants as distinguished from the artificial systems that were then in use, though he recognized that even the rules for formulating such a system were unknown to him. He used an artificial system by which he classified the higher plants on the basis of the number and grouping of the stamens and carpels of the flower. In his time there was little exact knowledge about plants that do not produce seeds.

Linnæus put into use the binomial system, which is still employed in naming both plants and animals. Nearly a hundred years before his time use had been made of two names as a substitute for the long descriptive phrases and sentences by which plants had been designated, but Linnæus popularized the binomial system and its general use dates from his time. He is an outstanding figure of his time because he gathered together and put into systematic form the work of earlier botanists, broadened by knowledge gained in his travels, described plants with remarkable skill, named them according to a convenient system, recognized the imperfections of his own system, and pointed the way, though he saw it indistinctly, to a natural system. He insisted, however, on the doctrine of the constancy of species, believing that though varieties might be the result of cultivation, the genus and the species were always the result of Nature and remained constant. This dogmatic view, to a certain extent, hindered the progress of botany for a long time afterward. Though Linnæus is regarded by some as the end of an old regime and by others as the beginning of

a new one, there is general agreement that the important progress toward modern botany dates from his time.

Progress in the Various Fields of Botany.—Botany is the science that includes all lines of inquiry about plants. Botanists are engaged in the work of securing facts about plants, arranging these facts so as to build up concepts and using these concepts in such a way as to tend to bring out general laws. A very brief survey of some of the steps in the progress of botany may be made under the following heads: taxonomy, morphology, paleobotany, anatomy, physiology, cytology, ecology, pathology, genetics, plant geography, and economic botany.

Taxonomy.—Taxonomy is concerned with the naming and classification of plants. Classification has progressed by slow steps from Aristotle's grouping of plants as trees, shrubs, and herbs to the present grouping into families, and the arrangement of these families in a sequence which at least approximates their natural relationships. Many artificial systems were used in which seed plants were grouped on the basis of some one or two characters, but it was seen that this plan grouped together plants that were quite dissimilar in many particulars, and there were many gropings toward a natural system. The sequence of families arranged by the German botanist, Engler, about 1887 marked a milestone in this progress. There is not, however, complete agreement with all the principles that he used, and many suggestions have been made of better arrangements. Efforts are being made at the present time with some success to put taxonomy on an experimental and genetic basis. The binomial system popularized among botanists by Linnæus was a natural growth and is fundamental in modern botany.

Morphology.—Morphology is the study of the form of the plant and its organs, emphasizing the forms assumed by the same organ in a series of plants. The study of the life history of a plant is an essential part of morphology. This consists in tracing the series of events from some one stage of the plant until it again arrives at the same stage. For example, we may begin with the seed of the bean and trace the life of the plant until it produces seeds. The study of

life histories and the comparison of the various forms of organs in series of plants make up morphology. It concerns itself with both the reproductive phase and the vegetative phase of the plant. It is evident, of course, that progress in morphology aids in taxonomy, and may result in changes in both classification and naming. Morphology was little studied apart from taxonomy until about 1650. About the middle of the nineteenth century the investigations of Hofmeister broke down the barrier that had previously existed between the higher and the lower plants, and thus opened the way for remarkable progress in morphology. Morphology is the basis for the study of the evolution of plants.

Paleobotany.—Paleobotany comprises the study of fossil plants. It has contributed much to the understanding of geology and has resulted in the bridging of some gaps in the plant kingdom, so far as this kingdom is at present represented by living plants. The discovery of fossil plants showing characters intermediate between the ferns and the seed plants is an example. Paleobotany originated in the early years of the nineteenth century, became much more appreciated about fifty years later, and has seen great progress in our own time.

Plant Anatomy.—The word anatomy is too familiar to need definition. Many facts about the gross anatomy of plants were known to Theophrastus, and progress in microscopic anatomy became notable in the latter half of the seventeenth century. Some of the early work on plant anatomy was from the physiological point of view and was largely concerned with an effort to find how far the tissues and functions of plants and animals were similar. Plant anatomy has contributed much to the progress of morphology and taxonomy, and is now one of the fundamentals of plant physiology.

Plant Physiology.—Plant physiology is the study of the functions of plants. Though plants were at least tacitly recognized as living things even in ancient times, experimental investigation of their functions did not make important progress until about the close of the eighteenth century.

Among the important fields of plant physiology are: (1) nutrition; (2) growth; (3) reproduction; (4) the response of the plant to its environment; (5) the interrelation of the organs and tissues of the individual plant; and (6) the energy relations of the plant.

Nutrition includes the entrance of water and of dissolved substances into the plant and their rise to its higher parts, the gaseous exchanges between the plant and the air, and the manufacture and use of foods in the plant. One of the earliest experiments in plant physiology was performed by Van Helmont (1577–1644), a Flemish physician and chemist, in an effort to determine the nature and source of the materials that make up the plant. He took a willow cutting weighing 5 pounds, placed it in a tub in a quantity of earth which when dried weighed 200 pounds, and watered it with rain water for five years, keeping the soil covered to protect it from dust. At the end of this time he found that the cutting had gained 160 pounds, while the soil, when again dried, had lost only a few ounces. From this he concluded that the plant was nothing but transformed water. His error in this conclusion consisted, of course, in neglecting to consider the air as a source of carbon dioxide. This gas was unknown at the time.

The rediscovery of oxygen by Priestley and the study of this gas and of carbon dioxide by other workers led early in the nineteenth century to an understanding of the exchanges of gases between the plant and the air, and this, with the final passing of the phlogiston theory in chemistry, according to which fire was thought to be a material substance, and the coming in of the concept of oxidation as a chemical process, gave great impetus to the study of plant nutrition. Great advances in the study of nutrition have come in our own time on the basis of increased knowledge of the chemistry of sugars, chlorophyll, and other organic compounds in plants. The study of the entrance into plants of water and of substances dissolved in it, was put on a scientific basis by study of the nature of plant cells and of the processes of osmosis and imbibition. The rise of water in tall plants is studied in the light of these two processes, the

physical properties of columns of water, and the anatomy of the plant, and has engaged during recent years the attention of workers trained in physics and in botany.

The study of growth includes the formation of cells, their increase in size, the changes in the cells which accompany and follow this increase, and the influence of the factors in the environment, such as heat, light, water, oxygen, and gravity on these processes. The critical study of growth in relation to the factors in the environment is a recent development.

Reproduction includes vegetative propagation and the production of new individuals by seeds and spores. The most rapid progress in this field has been made in recent years, although there has been a good deal of general knowledge about the reproduction of plants since ancient times.

The organs of the plant respond to the factors in the environment, such as those enumerated under growth, and the orientation of the plant with reference to these factors is an important phase of modern botany. A pioneer investigation of the response of plants to their environment was that of Knight early in the nineteenth century on the response of plants to gravity. He showed that this force is very important in determining the position assumed by the plant and laid the foundations for investigations of this subject, many of which have been made in our own time. Responses to other factors, such as heat, water, and the intensity, direction, and wave length of light have been carefully studied in recent years in the light of plant anatomy, the nature of the plant cells and of physico-chemical knowledge.

If we are really to understand the plant as an organism we must study the interrelation of its organs and tissues, in addition to the study of the individual organs and their functions. This relation is called correlation and involves the study of the organism as a whole.

An understanding of the energy relations of plants involves a knowledge of the reception of energy from the sun, and the use, storage, and releasal of this energy by the plant. Our own time has seen the first real attempts to produce a balance

sheet of the receipt of energy by the plant and of the various ways in which this energy is used or otherwise disposed of.

Cytology.—Cytology is the study of the nature of plant cells. In this field a good deal of emphasis is laid on the nature of the nucleus and the changes that it undergoes during division, though due attention is given to all parts of the cell, including the nature of protoplasm and of its surfaces, the structure and composition of cell walls, and protoplasmic communications between cells. Our knowledge of plant cells dates from Hooke's first sight of them through his microscope, and has increased as microscopes were improved and as we have learned more about cutting thin sections, and staining and mounting them. A new outlook was given to the study of cells about 1850 by the general recognition of the fact that all organisms are composed of cells and that all cells so far as we know them are formed by the division of preëxisting cells. About 1900 new impetus was given to the study of cytology by the recognition of the colloidal nature of protoplasm, and many facts otherwise irreconcilable were unified by this point of view. The invention and perfection of instruments for the dissection of cells under the microscope has recently contributed much to our knowledge of cells, and the comparative study of plant and animal cells has broadened our vision.

Ecology.—Ecology (see p. 339) is the study of organisms in relation to their environment. Plant ecology is sometimes thought of as merely the grosser physiology of plants as individuals and as associated in communities, but is now recognized as including a careful determination of the physical and chemical factors in the environment, such as light, heat, water, and other factors and of the mutual effects of plants and other organisms in the habitat. We usually think of it as originating with publications by Warming, beginning in 1895, though Theophrastus in the third century B.C. showed a knowledge of the rudiments of this sub-science. We have now accumulated a large mass of facts on the relation of plants to their environment and considerable progress has been made in making inferences from these. Plant ecology and animal ecology have been mutu-

ally helpful and some knowledge of both fields is highly desirable for the study of either.

Plant Pathology.—Plant pathology is the study of the diseases of plants, and has received more or less attention since very ancient times. Modern plant pathology is based on the recognition of fungi, bacteria and other microörganisms as the causative agents of plant diseases. Two important lines of investigation, the life histories of the pathogenic organisms and the relations between the host and the parasite, go hand in hand in pathological studies at the present time. The causal relation of the fungi in plant diseases was established in Germany about 1850 and of bacteria in the United States about 1880.

In recent years it has been established that some diseased conditions in plants are purely physiological and are not caused by organisms. An important phase of the study of plant diseases caused by organisms is now the development of plants that are immune to the attacks of these organisms. This work has emphasized the relation of genetics to pathology. The study of the relation of the host and the parasite has come to depend on a knowledge of the physiology of both, and the relation of pathology and physiology has thus become an intimate one. Obviously the morphology and anatomy of the host plant must also be known, and some knowledge of its ecology is desirable. It is thus evident that pathology is most advantageously studied in the light of a knowledge of the whole field of botany. Investigations in plant pathology are of very great economic importance and the considerable amount of money invested in the work has yielded good returns.

Plant Genetics.—Genetics deals with heredity. A large body of facts about the inheritance of characters by plants has been established, and considerable progress has been made in making inferences from them. Mendel's law, arrived at by the study of the inheritance of characters in peas, was published in an obscure journal in 1860, and its rediscovery about 1900 stimulated much work on genetics. Breadth of view has been given to the study of genetics by the consideration of both plants and animals. The study of the formation

of chromosomes in the dividing nucleus goes along with the experimental breeding of plants and animals in the progress of genetics. Plant breeding is practised as an art for economic reasons and also as a part of research in pure science.

Plant Geography.—Plant geography deals with the general distribution of plants on the earth and the factors to which this distribution is related. Obviously an acquaintance with the various species of plants is the starting point. Theophrastus knew about 500 plants; the herbalists of the sixteenth century about 2000, while about 300,000 are now known. The facts about the distribution of plants over the earth's surface have been accumulated by world-wide travelers, and attempts have been made to relate this distribution to present factors, such as soil, temperature, and light, and consideration has also been given to such facts of paleobotany as seem to bear on the case. Schimper's *Plant Geography on a Physiological Basis* was published in 1898 and many works on the subject have appeared since.

Economic Botany.—Economic botany deals with plants that are useful to man and with plants and other organisms that interfere with their growth. Interest in this phase of plants is, of course, very old. It involves the listing and discussion of useful plants, the study of the value of various crops, such as wheat, oats, corn, cotton, and timber, and may include the principles of plant production and some general account of plant diseases and of various factors that interfere with the growth of plants that are economically important.

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CHAPTER XXXII.

PLANTS AND HUMAN WELFARE.

PLANTS are the source of most of the necessities of existence and also of many of the conveniences which make life enjoyable. It is impossible to present in this chapter all of the particulars in which plants are related to human welfare. The general theme of the relation of plants to the necessities and pleasures of our lives is the important thing, and particulars find their place in illustrating this theme and making the relation clear and definite. The more important ways in which plants make human existence possible and enjoyable may be discussed under the following heads: (1) food; (2) clothing; (3) shelter; (4) industrial products; (5) energy; (6) regulation of water supply; (7) health; (8) comfort and pleasure. Not all plants, however, are favorable to human welfare. Among those that are a menace to man are: (1) microörganisms causing diseases of man, domestic animals, and crop plants; (2) microörganisms causing spoilage of foods; (3) poisonous plants; (4) weeds.

PLANTS FAVORABLE TO MAN.

All of our organic food comes directly or indirectly from plants. This is so obvious in the case of vegetable foods that it needs no discussion, and the plant origin of such articles as coffee and tea is well known. It is likewise clear that animal foods come indirectly from plants, since cattle, sheep, hogs, and poultry feed mainly on plants and plant products, and where animal food is concerned in their subsistence it is traceable to plants.

The dependence of fish and other aquatic animals on plant food is less obvious, but no less real. Some kinds of fish feed directly on plants, and others use animal food that is

dependent directly or indirectly on plant food. In many cases the food used consists of microscopic plants reproducing rapidly and occurring in enormous numbers in both fresh and salt water. The diatoms (see p. 191) are the commonest group of such plants.

Some fish (*e. g.*, sockeye salmon) feed directly on diatoms, while the food of others is readily traceable through several steps to diatoms as the primary source of food. The food cycle of the hake, a fish common in the sea along the east coast of the United States, was investigated by cutting open the stomachs and identifying the contents. These stomachs were found to contain young herring, and the stomachs of these herring were found to contain small animals called copepods. When these copepods were examined microscopically they were found to have taken diatoms as their food. The investigator sums up the case by saying, "No diatoms, no hake." Some fish feed directly on larger plants. Carp eat the leaves of aquatic plants, and some milkfish feed on filamentous green algæ. The food of other aquatic animals, such as oysters, clams, and crabs is also readily traceable to plants, mainly microscopic in size.

Plants furnish many of the materials used in the manufacture of our clothing and others are derived from animals which feed directly or indirectly on plant food. The direct origin of cotton and linen from plants is well known and the indirect origin of wool, silk, and leather is readily traced. During recent years much progress has been made in the manufacture of artificial fibers from plant materials, and many articles of clothing are now made directly from these or from cloth woven from them.

A good deal of the material that enters into our shelters is made from plants. A large part of this consists of lumber and timbers from trees. Many fiber products are now prepared from waste wood as well as from other plants (*e. g.*, corn and sugar cane), and these are much used in the interior of buildings. More primitive shelters are often made by the use of such plant parts as stems, leaves, and bark.

Man is dependent on plants for many important industrial products. Among these are rubber, paper, vulcanized fibers,

and alcohol. Rubber is obtained from the milky juice of trees, mostly of the spurge family. The juice was formerly obtained from trees growing wild, but many plantations of rubber trees have now been established in tropical regions. The guayule shrub of Mexico has also been found to be a source of rubber, though it is not used commercially at present. The preparation of rubber from this shrub involves the destruction of the plants, while the juice can be obtained from trees without killing them.

Much of the paper used in printing is made from wood pulp. Cottonwood and spruce are especially suitable for the preparation of wood pulp, but several other woods are now used. Some paper is made from rags and these are, of course, of plant origin. Vulcanized plant fibers are now used in industry in many ways. The handles of many tools and instruments are made from such material as are also gear wheels and other parts of machines. Alcohol finds many industrial uses in modern life. It is the product of the fermentation of plant products by microörganisms.

The regulation of the flow of water for the supply of cities is an important contribution of plants to human welfare. The mossy growth in the forest holds the water from rainfall and melting snow and allows it to run off gradually, where it runs off rapidly and is wasted when the forest is removed.

The use of energy other than that of their own hands is, of course, very important to human beings. Energy from coal, crude oil, petroleum, gasoline, and wood are necessary for the maintenance of our present industrial system and habits of living, and will play a large part in such progress in these lines as may come in the future. We use the energy largely in three ways—to drive machinery and to provide heat and light. Coal is formed by slow changes through long periods of time in organic matter, mainly the remains of plants. Whatever animal remains have entered into the formation of coal are, of course, traceable to plants, since all animals are dependent ultimately on plant food. Coal is the source of much energy used in transportation, industrial processes, and providing heat and light. Crude oil comes from the decomposition of vegetable and animal matter, and is thus

traceable to plants. It is refined into the kerosene, gasoline, distillate, and other products which so largely provide energy and light. Illuminating gas is made by the distillation of coal. Wood is much used for heat, and to a certain extent for energy in industrial processes.

Many of the medicines used in the treatment of diseases are of plant origin. Quinine and digitalis are examples. A considerable number of medicines are now made synthetically, but still a large number of common drugs are prepared directly from plants. Several hundred drugs that are official in the United States are of plant origin, and a large number of unofficial ones that are commonly used also come from plants. Many substances used in the preservation of health are also of plant origin. Among the common agents of sterilization and disinfection are carbolic acid from coal-tar and formaldehyde from wood.

We also derive much comfort and pleasure from plants. The shade of trees does much to make life tolerable in many parts of the world. We enjoy the beauty of form and color of plants, and are pleasantly stimulated by the renewal of their growth in spring. Much beauty is added to the surface of the earth by its natural cover of vegetation. The ugliness of a region over which a forest fire has passed or of a recent cut or fill makes us conscious of the beauty of plants as a covering. We make ugly places beautiful by landscape effects and flower gardens. We derive much pleasure not only from such finished products but also from planning, planting, and caring for them.

PLANTS UNFAVORABLE TO MAN.

Many plants interfere with the health and pleasure of people and also cause large economic losses. Microörganisms causing human diseases are among the most important of these. Tuberculosis is a widespread disease causing much distress and many deaths as well as costing huge sums of money. It was definitely established in 1884 that this disease is caused by a specific organism (*Mycobacterium tuberculosis*). It has been found that tuberculosis is curable

if treatment is begun in the very early stages of the disease. Great progress has been made in recent years in the care and treatment of persons afflicted with this disease and also in preventing contagion, so that it is much less to be dreaded than it was a few years ago.

Typhoid fever is another widespread disease due to a specific organism. The typhoid bacillus (*Eberthella typhi*) was discovered in 1880, grown in pure culture in 1884, and, after this, evidence that it is the cause of typhoid fever gradually accumulated until certainty was established. This disease may be spread by drinking water and also by milk and other foods. Since the nature of the disease and the ways in which it is carried have become known, effective measures of preventing its spread have been found, and epidemics of it are less common than formerly. There are many other human diseases, either caused by specific micro-organisms or with which such organisms are associated in some way. Among these are whooping-cough, scarlet fever, cholera, pneumonia, diphtheria, lockjaw, and botulism.

Man's fight against infectious diseases has in the main been a winning one. The ignorance and superstition of the past have been replaced by a scientific point of view and definite knowledge of the causes and nature of diseases. Progress in this fight has been marked by much self-sacrifice among those engaged in the work, and several workers have sacrificed their lives that facts about diseases might be definitely established. We do not yet have complete knowledge, however, and much still remains to be done.

A number of infectious diseases of domestic animals cause large economic losses. Tuberculosis occurs among cattle, hogs, and other animals. This disease can be communicated from cows to human beings who use the milk. A reliable test for bovine tuberculosis has been devised, and governmental measures have been taken for the removal of infected cows from dairy herds. Hog cholera is another important disease. The organism causing it was discovered in 1885, and the understanding of the nature of the disease has considerably lessened the economic losses caused by it.

Plants are subject to many diseases, most of which are due to bacteria or other fungi, though some are due to purely physiological conditions independent of microörganisms. About 30 diseases of plants are known to be caused by bacteria, and the number caused by rusts, mildews, and smuts is much larger. Among the bacterial diseases of plant are cucumber wilt, blackrot of cabbage, and fire blight of pear and apple trees. Among the plant diseases due to other fungi are wheat rust, corn smut, chestnut blight, and white pine blister rust. Further discussion of plant diseases will be found in Chapter XIV.

Spoilage of foods is largely due to microörganisms, and we prevent their activities by such means as canning, pickling, drying, and cold-storage. The canning of food has been practised for over a hundred years, and during the last thirty years it has assumed major importance in preserving foods for seasons of the year when they cannot be obtained fresh and in distributing many foods to places where they cannot be easily produced. Pickling in brine is used as a means of preserving many foods (*e. g.*, fish). Fruits and other foods are very commonly preserved by drying. Freezing is a common means of preserving fish. Many foods are kept for a short time in cold-storage.

Some plants are poisonous to man. Mushrooms are highly prized as human food, but, unfortunately, a number of species are poisonous. There are a large number of wholesome ones, but ability to distinguish these from the poisonous kinds is always necessary in selecting mushrooms for food. The leaves of some plants are used as greens, and, unfortunately, some poisonous plants at certain stages of their development resemble the wholesome ones commonly used. Some common plants are poisonous to domestic animals. The death of cattle from eating poison hemlock, wild carrot, and other related plants is common. The book by Pammel included in the list at the end of this chapter contains full information on plants poisonous to man and domestic animals.

Weeds are always a menace to crops and ornamental plants

and are thus a source of expense and annoyance to man. Any plant that is growing where man does not want it may be considered a weed. Weeds may injure desirable plants by shading them, by using up the nutrients in the soil, or by exhausting the soil moisture which would otherwise be available for desirable plants. Weeds may also be objectionable because they are unsightly.

Pigweed (*Amaranthus retroflexus*) is a coarse annual weed which is common in cultivated fields and gardens. It produces numerous small seeds and an effective way of dealing with it is to kill the plants before they produce seeds. The Canadian thistle (*Cirsium arvense*) is a troublesome weed introduced from Europe. It has creeping, perennial rootstocks which form extensive growths in the soil and it is thus difficult to eradicate. It belongs to the composite family, and its seeds have the tuft of hairs characteristic of seeds of that family, and this enables them to be widely distributed by wind.

The Russian thistle (*Salsola Kali* var. *tenuifolia*) is a much-branched, annual weed introduced into the Dakotas and other states about 1885. It branches profusely, giving the plant a hemispherical form, and the branches become spiny when the plants become dry in autumn. The root is slender and the whole plants break loose from the soil in early fall and are rolled across the prairie in great numbers. The seeds are thus scattered widely. The best method of getting rid of it is to kill the plants by cultivation before the seeds are ripe. Dodder is a pest weed that has caused much loss to growers of alfalfa and other crops. It is described on p. 364.

These are only a few examples of the many troublesome weeds with which farmers and gardeners must contend. Knowledge obtained by careful study of the growth habits and method of propagation of the various weeds has greatly aided in the battle against them, but constant warfare is necessary in order to provide good conditions for the plants that we desire and keep out the ones that we do not want.

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18. See also the list at the end of Chapter XIV.

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